The Geology of the Upper Mississippi Valley Zinc-Lead District

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CONTENTS

Page

- Abstract 1
- Introduction 2
  - General features of the region 2
    - Location 2
    - Climate and vegetation 3
    - General geography 3
    - Cultural development and facilities related to mining 3
  - Field work and acknowledgments 3
  - Scope of the report 5
  - Previous geologic work in the district 5
- Geology 6
  - Stratigraphy 6
    - Precambrian rocks 6
    - Cambrian system 6
      - Upper Cambrian series 6
    - Ordovician system 9
      - Lower Ordovician series 9
        - Prairie du Chien group 9
      - Middle Ordovician series 9
        - St. Peter sandstone 9
        - Platteville formation 10
        - Decorah formation 14
        - Galena dolomite 17
      - Upper Ordovician series 18
        - Maquoketa shale 18
    - Silurian system 19
    - Deposits of post-Silurian and possibly pre-Pleistocene age 19
    - Pleistocene epoch, by A. E. Flint 20
      - Deposits of glacial origin 20
        - Glaciofluvial sediments 20
        - Drift 20
        - Loess deposits 20
    - Recent sediments, by A. F. Agnew 21
  - Physiography, by A. E. Flint 21
    - Topography 21
      - Upland 21
      - Valleys 21
      - Mounds 22
      - Mississippi River gorge 23
    - Drainage 23
    - Terraces 24
      - Depositional terraces 24
      - Erosional terraces 25
    - Caves and sinks 25
- Structure 26
  - General features 26
  - Regional relations 26
  - Structures of the mining district 27
    - Folds 27
      - First-order folds 29
      - Second-order folds 31
      - Third-order folds 34
      - Summary of folds 35
    - Faults 35
      - Major faults 35
      - Minor faults 39
    - Joints 43
    - Sandstone dikes 46
    - Accentuation of structure by solution thinning 46
  - Origin and mode of formation of the structure 49
    - Summary of previously held ideas 49
    - Proposed interpretation 52
      - Orogenic disturbances in the North-Central States 52
      - Development of the structural features in the North-Central States 54

Page

- Structure—Continued
  - Origin and mode of formation of the structure—Con.
    - Proposed interpretation—Continued
      - Origin and development of the district structures 55
      - Development of the structural features within the district 55
      - Origin of the folds 56
      - Origin of the faults 58
      - Origin of the joints 62
      - Development of the structures controlling the ore bodies 63
    - Comparison with other viewpoints regarding the origin of structures within the district 66
- Ore deposits 67
  - History of mining 67
  - Production 72
    - Lead production 72
    - Zinc production 74
      - History of production 74
      - Production from zinc ore bodies 75
    - Copper production 79
    - Iron sulfide production 79
    - Barite production 80
    - Iron production 80
  - General features of the ore deposits 81
- Mineralogy 83
  - Detailed description of minerals 84
    - Native elements 84
      - Sulfur(S) 84
      - Gold(Au) 84
      - Copper(Cu) 84
    - Sulfides 84
      - Galena(PbS) 84
      - Chalcocite(Cu_2S) 84
      - Sphalerite(ZnS) 85
      - Greenockite(CdS) 85
      - Wurtzite(?) (ZnS) 85
      - Pyrrhotite(FeS) 86
      - Millerite(NiS) 86
      - Bornite(Cu_5FeS_4) 86
      - Chalcopyrite($CuFeS_2$) 86
      - Pyrite(FeS_2) 86
      - Cobaltite(?) ($CoAsS$) or Smaltite(?) ($CoAs_2$) 87
      - Marcasite(FeS_2) 87
      - Bravoite($(NiFe)S_2$) 88
      - Violarite($NiFeS_4$) 88
    - Oxides 88
      - Cuprite(Cu_2O) 88
      - Tenorite(CuO) 88
      - Hematite(Fe_2O_3) 88
      - Pyrolusite(MnO_2) 89
      - Limonite($2Fe_2O_3 \cdot 3H_2O$) 89
      - Psilomelane (amorphous mixture of various hydrated manganese oxides) 89
    - Carbonates 89
      - Calcite($CaCO_3$) 89
      - Dolomite($CaMg(CO_3)_2$) 90
      - Ankerite($Ca(Mg,Fe,Mn)(CO_3)_2$) 90
      - Smithsonite($ZnCO_3$) 90
      - Aragonite($CaCO_3$) 90
      - Cerussite($PbCO_3$) 91
      - Malachite($CuCO_3 \cdot Cu(OH)_2$) 91
      - Azurite($2CuCO_3 \cdot Cu(OH)_2$) 91
      - Aurichalcite($(2Zn,Cu)CO_3 \cdot 3ZnCu)(OH)_2$) 91
      - Hydrozincite($2ZnCO_3 \cdot 3Zn(OH_2)$) 91

Page
Mineralogy—Continued
Detailed description of minerals—Continued
Silicates 91
Quartz(SiO_2) 91
Hemimorphite($Zn_2SiO_4.H_2O$) 92
Muscovite, variety sericite($(H,K)AlSiO_4$) 92
Sauconite($(Zn_{1.54}Mg_{.15}Al_{.18}Fe_{.23})(Al_{.61}Si_{3.39})O_{10}(OH)_2Ca/2_{.18}K_{.02}$) 92
Glauconite (essentially a hydrous silicate of iron and potassium) 92
Zincian montmorillonite 93
Phosphates and arsenates 93
Pyromorphite($Pb_5Cl(PO_4)_3$) 93
Erythrite($Co_3(AsO_4)_2{\cdot}8H_2O$) 93
Sulfates 93
Barite($BaSO_4$) 93
Anglesite($PbSO_4$) 93
Gypsum($CaSO_4{\cdot}2H_2O$) 93
Epsomite($MgSO_4{\cdot}7H_2O$) 93
Goslarite($ZnSO_4{\cdot}7H_2O$) 94
Melanterite($FeSO_4{\cdot}7H_2O$) 94
Copiapite($Fe_2(FeOH)_2(SO_4)_5{\cdot}17H_2O$) 94
"Honessite" (hydrous basic nickel iron sulfate) 94
Elements present in small quantities in the ores 94
Paragenesis 96
Premineralization relations 96
Relations during ore deposition 96
Quartz stage 96
Dolomite stage 97
Solution stage 97
Pyrite stage 98
Marcasite stage 98
Early platy barite stage 99
Sphalerite(and wurtzite?) stage 99
Cobaltite(?) or smaltite(?) stage 99
Galena stage 99
Late barite stage 99
Chalcopyrite-millerite stage 99
Calcite stage 100
Postmineralization relations 101
Wall-rock alteration associated with the ore deposits 101
Solution of the carbonate rocks 102
Silicification 105
Dolomitization 107
Less common wall-rock alterations 108
Details of structures and textures of the ore bodies 108
Ore-body relations in the rocks of Middle Ordovician age 108
Fault-controlled, pitch-and-flat ore bodies 109
Arcuate ore bodies 109
First stage 109
Second stage 115
Third stage 119
Linear ore bodies 123
First stage 123
Second and third stages 125
Gash-vein, joint-controlled ore bodies 128
Placer and residual deposits 130
Occurrence and textures of the ores in the rocks of Middle Ordovician age 131
Vein fillings and replacement veins along fractures and bedding planes 131
Cavity fillings in fault breccias and fractured zones 133
Cavity fillings in solution breccias 133
Disseminations by replacement and impregnation deposits in favorable beds 134
Ore-body relations in the Cambrian, Lower and Upper Ordovician and Silurian rocks 135
Mineral deposits in the Cambrian rocks 135
Mineral deposits in the Prairie du Chien group 136
Mineral deposits in the St. Peter sandstone 137
Mineral deposits in the Maquoketa formation 137
Mineral deposits in dolomite of Silurian age 138

Page
Relations between ore deposition and larger geologic features 138
Geologic relations of the district boundaries 138
Distribution of the ore deposits within the district 139
Ore deposits and the larger folds 140
Arrangement of the ore-bearing joints 140
Ore deposition and fractures 141
Zonation of the ore deposits in the Upper Mississippi Valley district 141
Regional horizontal zoning 142
Local horizontal zoning related to centers of more intense mineralization 144
Vertical zoning in relation to the entire mineralized stratigraphic sequence 144
Vertical and horizontal zoning within individual ore deposits 145
Origin of the ores 146
Evidence for the magmatic hypothesis 146
Historical résumé 147
Proposal of the magmatic hypothesis 147
Proposal of the meteoric hypothesis 148
Development of variations in the magmatic and meteoric hypotheses 148
Proposal of the artesian circulation hypothesis 149
General acceptance of the meteoric and artesian circulation hypotheses 149
Return to the magmatic hypothesis 150
Summary 152
Discussion of the origin of the ores 153
Meteoric hypothesis 153
Difficulties of the meteoric hypothesis 155
The magmatic hypothesis 157
Conclusions 163
Secondary changes in the ore deposits 164
Zone of leaching and oxidation 164
Zone of enrichment 166
Secondary oxides 166
Secondary sulfides 166
Geologic principles applied to exploration and mining 167
Older prospecting methods 167
Stratigraphy and structure and other features as guides in exploration 168
Stratigraphy 168
Useful marker strata 168
Depths to which drilling should proceed 170
Prospecting beneath areas capped by Maquoketa shale 170
Structure 170
Importance of folds of first order 170
Importance of folds of second order 171
Suggested methods of prospecting 172
Prospecting for zinc ore bodies 172
Prospecting for lead ore bodies 173
Geophysical and geochemical prospecting methods 174
Use of structures within the ore bodies in mining exploration 174
Correlation of surface outcrops and drill logs as guides to structure and ore bodies 174
Use of geology to delimit ore bodies during prospecting 174
Mines in the upper Mississippi Valley zinc-lead district 175
Mines in the main part of the mineralized district 175
Mines in Illinois 175
Elizabeth subdistrict 175
Wishon mine 175
Haggerty mine 176
Illinois mine 176
Kansas mine 176
Skene mine 176
Apple River–Warren subdistrict 176
Stockton, Simmons Mound, Morseville subdistricts 176
Scales Mound subdistrict 176
Rockford Mining and Milling Co. mine 176
Glanville prospect 176

	Page
Mines in the upper Mississippi Valley—Continued	
Mines in the main part of the mineralized district—Continued	
Mines in Illinois—Continued	
Galena subdistrict	176
Pittsburg or Great Western mine	178
Marsden Black Jack mine	178
Amelia mine	178
Bautsch mine	178
Gray mine	180
Royal Princess mine	180
Oldenberg mine	182
Waters mine	182
Little Corporal mine	182
Merry Widow and Ten Strike mines	182
Betsy mine	182
Buck Lead range	182
The Blewett mine	182
Appleton mine	183
Pilot Knob mine	183
Graham-Snyder mine	183
Hoosier mine	183
North Unity mine	183
Vinegar Hill mine	183
Unity or South Unity mine	184
Hughlett and Gray mine	184
Northwestern mine	184
Birkbeck mine	184
Graham-Ginte mine	186
Mines in Wisconsin	186
Hazel Green-Shullsburg subdistrict	186
Tommy Dodd mine	187
Jefferson mine	187
Hazel Green mine	187
Honest Bob mine	188
Scrabble Creek mine	188
Madison mine	188
Crawford mine	188
Etna mine and Appleby or Looney Level	189
Pittsburg-Benton mine	189
Corr and Crooked Six mines	189
McCabe mine	190
Kivlahan mine	190
McCann mine	190
New Calvert or "Soft" Calvert mine	190
North Star or Ralph mine	190
Bull Moose and Middie mines	191
Treganza, Frontier, and Calvert mines	191
Hird No. 1 mine	191
Century mine	193
Kearns mine	193
Oregon or Milner mine	193
Quinlan diggings	193
Coltman mine	193
Swift and Rooney mine	194
Ewing and Cook mine	194
Weiskircher mine	194
Imperial, Hoover, or Iowa mine	194
Old Cottingham mine	194
New Cottingham mine	196
Little Minnie mine	196
Empress mine	196
New Hoskins mine	196
Hoskins-Fields mine or Hoskins mine	197
Meloy (Fields-Meloy) and Robson mines	197
Jug Handle mine	197
Farrey and Benton Star mines	198
Drum mine	198
Nightingale mine	198
Leadmine or Howe and Alderson mine, or Leekley level	198
New Ida Blende mine	199
Old Ida-Blende mine	199
Martin mine	200
Whaley mine	200
Victory mine	200
Jack of Clubs (Dawson or Lafayette) mine	200
Mines in the upper Mississippi Valley—Continued	
Mines in the main part of the mineralized district—Continued	
Mines in Wisconsin—Continued	
Hazel Green-Shullsburg subdistrict—Con.	
Hird No. 2 mine	200
Bearcat, or Hird No. 3 mine	200
Kittoe mine	200
New Birkett mine	202
Birkett mine	202
Byrnes mine	202
Mermaid mine	203
Murphy mine (also Last Chance or Bininger)	203
Monmouth and North Monmouth mines	203
Trewartha mine	203
Strawberry Blonde mines	204
Consolidated mine	204
Jack of Diamonds mine	204
Ollie Bell mine (Kerwin mine, Curwin and Miller mine, or Leekley mine)	204
Curwen mine	205
Sally Waters or Monarch mine	205
Penna-Benton mine and Expansion mine	205
Lafayette (Lake Superior) mine	207
Lucky Twelve mine	207
Indian Mound or Murphy mine	207
C. A. T. mine	207
Fields "Upper Run" mine	207
Monroe, Longhorn, and Little Joe mines	209
Blackstone mine	209
Champion and Eureka mines	210
American Zinc Thompson mine	210
Old Occidental mine	210
Longhenry or Spensley mine	210
Fox mine	211
Kennedy (Mills, Hoskins) mine	211
Badger mine	212
Lawrence mine	213
Cleveland mine	213
McMillan mine	214
Federal mine	214
Tunnel Hill mine	214
Little Dad mine	214
Big Dad mine	214
Richards or Berg mine	214
Rowley mine	215
New Occidental mine	215
B and C mine	215
Coughlin or Murphy mine	215
Boyle, Hardy, or Hofer mine	216
Oakland Level, Brady mine, and McFeeley Level	216
Little Giant (formerly the Drybone Diggings) and Galena Level (Butler) mine	216
Little Bennie mine, McPhee Level or Moore's Level	218
DeRocher mine	218
Ernest and Myers Level	219
Nip and Tuck or Giles mine	219
Helena-Roachdale, Blain and Logan, and Expansion Level mines	219
Expansion mine	220
James, New Harty, and Mullen mines	220
Old Mulcahy mine	221
New Mulcahy mine	221
Copeland mine	221
O'Brien mine	224
New Mullen mine	224
Wipet, Winskell-Peterson, New Winskell or Winskell No. 3 mine	224
Winrock, Rock, or Winskell No. 2 mine	224
B. A. T. mine	224
Booty mine	225
Old Winskell or Winskell No. 1 mine	225

	Page
Mines in the upper Mississippi Valley—Continued	
Mines in the main part of the mineralized district—Continued	
Mines in Wisconsin—Continued	
Hazel Green-Shullsburg subdistrict—Con.	
Andrews mine	225
Mulcahy mine	225
Lyne or Winskell No. 4 mine	227
Calumet and Hecla mine	227
Vinegar Hill Blackstone mine	227
Thompson (Fields-Thompson) mine	227
Crawhall mine	228
New Longhorn or Ed Longhorn mine	228
Annie Walton mine	228
Wilkinson mine	230
Lucky Hit (New Lucky Hit) mine	230
Paquette mine	230
Rodham mine	231
Milwaukee-Shullsburg or Rowe mine	231
James Rowe Lead mine	231
Gratiot Copper mine	231
Meekers Grove (Jenkinsville) subdistrict	232
Jarrett or M and D mine	232
Wicklow or Reliable mine	233
Board of Trade mine	233
Little Dick mine	233
Best mine	233
Big Dick mine	233
Connecting Link No. 1 and No. 2 mines	234
Liberty mine	234
Koll mine	234
Lawrence mine	234
Uniset or Meekers Grove Opencut mine	234
Big Ten mine	234
Masbruch mine	236
Depp (or Fever River) mine	236
Midway mine	236
Cuba City mine	236
Henrietta mine	236
Gritty-six mine	236
Raisbeck mine, Buzzard's Roost diggings, and Big Bill mine	237
Trego-Anthony mine	237
Meekers Grove mine	237
Dall mine and Cook prospect	237
Vandeventer mine	238
Rico mine	238
Pittsburg mine	238
Roosevelt mine	239
James and Little Elm mines	239
Pine Tree mine	239
Baxter mine	239
Porter Barite mines	241
Big Patch subdistrict	241
Beloit Elmo mine	241
Black Hawk, Spink, and Big Patch mines	241
Peaceful Valley mine	241
Lyght mine	242
Platteville subdistrict	242
Blockhouse Range	242
Weigle mine	243
Goke-Blockhouse mine	243
Cruson mine	243
Old Blockhouse mine	243
Big Jack mine	243
Roseleip, Hi-Spot or New Blockhouse mine	244
Vinegar Hill Blockhouse mine	244
Kistler and Stephens mine	244
Seitz or New East End mine	244
East End mine	244
Klar-Piquette mine	245
St. Rose and New Rose mines	246
Little Grant, Klondike, Brunton or Weigle mine	246

	Page
Mines in the upper Mississippi Valley—Continued	
Mines in the main part of the mineralized district—Continued	
Mines in Wisconsin—Continued	
Platteville subdistrict—Continued	
Whig Patch and area west of Platteville	246
Tippecanoe mine	246
Whig and Edgerton mines	247
Western Star mine	247
Capitola, or Philips and Rice mine	247
Graham and Stephens mine	247
M and H mine	247
West Hill mine	247
Mines east and north of Platteville	248
Hodge mine	248
Enterprise and Empire mines	248
West Empire mine	248
Hibernia mine	248
Trego-Great Northern mine	248
Columbia mine	250
Grant County (Lucky-Four) and Homestead mines	250
Royal mine	250
Acme mine	251
Mitchell Hollow mines	251
Beacon Light mine	251
Kingeter mine	251
Calamine-Truman-Darlington subdistrict	251
Southwestern Wisconsin	252
M. C. mine	252
Potosi subdistrict	252
Tiffany mine	253
Pleumer Level	253
Piquette mine	253
Tennyson mine	253
Preston Point Level mine	253
Trego No. 2 mine	254
Wilson and Bootjack mines	254
Piquette prospect	254
Cardiff No. 2 mine	254
Krog and Webster mine	254
Cardiff No. 1 mine	255
Horseshoe mine	255
Little Horseshoe mine	255
Red Dog mine	255
Fairplay Subdistrict	255
Fairplay Level mine	256
Beetown subdistrict	256
Black Jack, Beetown zinc mine, or Wilcox diggings	256
Beetown mine	257
Atkinson mine or Muscalunge Level	257
Yellow Jacket mine	257
Eberle mine	257
Fennimore subdistrict	258
Mifflin-Cokerville subdistrict	258
Last Chance and LaFollette mines	259
Washburn mine	259
Crow Branch mine	259
Ebenezer mine	261
Coker No. 2 mine	261
Coker No. 1 mine	262
New Dale Rundell mine	262
Coker No. 3, and M. and A. or Big Tom mines	262
Senator mine	264
Defense and New Defense mines	264
Clayton mine	264
New Gruno mine	264
Old Gruno mine	265
Penitentiary or Black Jack mine	265
Old Slack mine	265
Okay, Slack, Peacock, Lucky-Six and Squirrel mines	265
Nigger Jim diggings	266

	Page
Mines in the upper Mississippi Valley—Continued	
Mines in the main part of the mineralized district—Continued	
Mines in Wisconsin—Continued	
Mineral Point-Linden-Dodgeville subdistrict	266
Lost Grove mines	267
John Vivian mine or Brown Range	267
Earl, Kodatz, and Brown mines	267
Paul Graber mine	268
Mineral Point mines	268
Hoare mine	268
Liverpool or Old Ross Mine	268
Ben Hur mine	268
Merry Christmas mine	268
Harris mine	268
Temby copper mine or Bracken mine	269
Beach copper mine	269
Wasley copper mine	269
Pierson prospect	269
Ansley copper mine	270
Chief of Police mine	270
Diamond Grove mines	270
Hazel Patch and Western mines	270
Tripoli mine	270
P. M. mine	270
Victoria or Advance mine	270
Argall mine	270
Linden mines	271
Gilman mine	271
Ross, Gribble and Stevens, and East Glanville mines	271
Trio or Pode mine	271
Dark Horse-Optimo No. 1 mine	272
Treloar or Harmony mine	272
Wicks mine	272
Vial mine	272
Rajah mine	273
Spring Hill mine	273
Spargo mine	273
Weigel mine	273
Silver Dollar mine	273
Linden Range	273
Optimo No. 2, part of Mason mine	274
Mason, Linden, or Heathcock mine	274
Glanville mine, also formerly Treglown and Captain Wicks, or Morrison diggings	274
Robarts (Hinkle), and Wildcat or Lucky Six No. 2 mine	274
Optimo No. 3 or Rolling mine	275
South Rule, Optimo No. 4 (Fearless), North Rule and Prairie mines	275
North Survey or Van Matres Survey mines	277
Joe Stegan or Duke Smith mine	277
Barreltown adits	277
North Survey mine	277
Dodgeville mines	277
Dodgeville No. 2 (Hospital Run) and Dodgeville No. 3 mines	277
Dodgeville No. 1, includes New D. H. and S., Ellis, Berryman, Lucky-Five and New McKinley mines	279
Old D. H. and S. or Stratman mine	279
Pengelly mine	279
McKinley mine	279
Tyrer mine	280
Four S. and B. mine	280
Oxman or Oxman and Owens mine, and Snowball mine	280
Simpson and McKinley-Simpson mines	280
Williams mine	280
Mines in the upper Mississippi Valley—Continued	
Mines in the main part of the mineralized district—Continued	
Mines in Wisconsin—Continued	
Mineral Point-Linden-Dodgeville subdistrict—Continued	
Dodgeville mines—Continued	
Hugh Jones mine, Hendy Gavey and Sobey and Co. mine	280
Porter Grove mines	280
Demby—Weist mines	280
Montfort subdistrict	282
Johns, Montfort, or Jones and Snow mine	282
O. P. David mine	283
United mine	283
Highland subdistrict	283
Red Jacket and Centerville mines, or Nundorf diggings	285
Steppler mine	285
St. Anthony mine	285
Kroll mine, Hornswoggle diggings, and Old St. Anthony mine	285
Ohlerking, or Oleking, or Moosan mine	285
Milwaukee-Highland mine	286
Wallace mine	286
Clark mines, including the Cherry Valley, Clark No. 2, Lampe-Eberle, Clark No. 3, and Clark No. 1 mines	286
Imhoff mine	287
Imhoff-Egan mine	287
Lewis or Lewis Bros. and Lynch mine	287
Highland mine, including Kennedy, Kennedy Drybone, Drybone Hollow, Franklin, Old Jack, and North Lewis mines	287
Minter mine	288
Happy Home mine	288
Eastern and Blue Minerals subdistricts	288
Newkirk or Aspen Grove mine	288
Brigham's mine	288
Mines in Iowa	288
Tete des Morts subdistrict	289
Dubuque subdistrict	289
Beadle, or Dubuque and Lake Superior mine	289
Brugh and Amsden mine	290
Fourteenth Street mine	290
Level mine, Kilbourne mine, and Karrick or Kerrick and Jones mine	290
Levens or North Langworthy mine	290
Stewarts Cave mine	290
Stewart and Bartlett mine	290
Durango Drybone mine, Timber Range or Ewings diggings	291
Bonson mine	291
Durango No. 1 mine	291
Sherrill's Mound subdistrict	291
North Buena Vista-Turkey River subdistrict	291
Fitzpatrick mine	292
Guttenberg subdistrict	292
Holmes and Kann mines	292
Mines in outlying parts of the district	292
Mines and prospects in Illinois	293
Mount Carroll area	293
Freeport area	293
Oneco diggings area	293
The Eleroy area	294
Staderman gold mine	294
Mines and prospects in Wisconsin	294
Little Grant lead diggings	294
Bridgeport quarry	294
Woodman lead mine	294
Little Kickapoo lead diggings	294
Wauzeka Ridge lead diggings	294
Plum Creek copper mine	294
Copper Creek mine	295
Readstown copper diggings	295
Cashtown copper occurrence	295

	Page
Mines in the upper Mississippi Valley—Continued	
Mines in the main part of the mineralized district—Continued	
Mines and prospects in Wisconsin—Continued	
Browns farm copper occurrence	295
Avoca copper occurrence	295
Orion lead mine	295
Akan lead mine	295
Sextonville lead diggings	295
Keyesville lead diggings	295
Pine Bluff lead diggings	295
Black Earth lead diggings	295
Rio lead diggings	295
Cambria lead diggings	295
Doylestown lead diggings	295
Ironton iron mine	295
Hagerman Hill hematite deposits	295
Mines and prospects in Iowa	295
Anamosa diggings	295
Clinton diggings	295
Lansing lead mine	295
Mineral Creek lead mines	296
Mine in Minnesota	296
Dresbach lead diggings	296
References	297
Index	305

ILLUSTRATIONS

[All plates are in map case]

PLATE 1. Map of the upper Mississippi Valley zinc-lead district.
2. Economic and geologic map of the Mifflin-Cokerville zinc-lead district.
3. Meekers Grove (Jenkinsville) zinc-lead area, Lafayette, Wis.
4. Geologic map of the Center Grove-Pikes Peak area, Dubuque County, Iowa.
5. Geologic structure map of the Hazel Green-Shullsburg zinc-lead area, Lafayette and Grant Counties, Wis.
6. Geologic structure map of the Potosi lead-zinc area, Grant County, Wis.
7. Geologic structure map of the Beetown lead-zinc area, Grant County, Wis.
8. Preliminary structure map of the upper Mississippi Valley district.
9. Map of the lead mines of the upper Mississippi Valley (1829).
10. Geologic map of the Dodgeville No. 1 mine.
11. Geologic map of the Trego mine.
12. Geologic map of the Hoskins mine.
13. Geologic map of the Federal mine.
14. Geologic map of the Martin mine.
15. Geologic map of the Liberty mine.
16. Geologic map of the Monroe-Longhorn mine including the North Monroe ore body.
17. Geologic map of the Wipet mine.
18. Geologic map of the B. A. T. mine.
19. Geologic map of the New Birkett mine.
20. Geologic map and cross sections of the Graham-Ginte mine.
21. Geologic maps of the Pittsburg-Benton, Hazel Green, and Durango Drybone mines.
22. Geologic map of the New Mulcahy mine and maps of Curwen, Last Chance, and New Dale Rundell mines.
23. Map of Helena-Roachdale mine.
24. Map of the Defense and New Defense mines.

	Page
FIGURE 1. Index map showing outline of principal mineralized area, and stratigraphic locations cited in text	7
2. Generalized stratigraphic column for zinc-lead district	8
3. Detailed stratigraphic column of Platteville, Decorah, and Galena formations in zinc-lead district	11
4. Pecatonica and McGregor members	13
5. Type section, Quimbys Mill member	14
6. Spechts Ferry and Guttenburg members	14
7. Strata of the Platteville, Decorah, and Galena formations	17
8. Maquoketa shale overlain by dolomite of Silurian age	19
9. Map of the Driftless Area of the upper Mississippi Valley zinc-lead district	22
10. Map showing Couler Valley, an abandoned stream channel of the Little Maquoketa and Mississippi Rivers	24
11. Map showing Apple River piracy	24
12. Generalized diagram showing the major structural features of the region bordering the upper Mississippi Valley district	28
13. Axial trends of the larger folds and faults in the upper Mississippi Valley district	29
14. Structural map of the folds and faults in the area 2 miles east of Meekers Grove, Wis	30
15. Axial-trend relations of the first-order folds in the district	31
16. Axial-trend relations of first order folds. *A*. In the west half of the district. *B*. In the east half of the district	22
17. Axial-trend relations of the second-order folds in the Hazel Green-Shullsburg area	32
18. Structure map of the area east of Hazel Green, Wis	33

Page

FIGURE 19. Axial-trend relations of third-order folds in the Hazel Green-Shullsburg area 34
20. Axial-trend relations of third-order folds. A. In the west half of the Hazel Green-Shullsburg area. B. In the east half of the Hazel Green-Shullsburg area 34
21. Vertical section across the north limb of the Mineral Point anticline 36
22. Sketch illustrating a reverse fault exposed 1 mile northwest of Hollandale, Wis 36
23. Geologic mine map and section showing the shear fault in the west end of the Liberty mine 38
24. Section illustrating relations of the bedding-plane fault with accompanying minor wedge faults exposed east of Tennyson, Wis 39
25. Photograph of main pitch reverse fault along west side of the Graham-Ginte mine 40
26. Idealized section of the fault and drag-fold relations on one limb of a typical zinc ore body in the district 40
27. Geologic structure map of the Coker mines 41
28. Map of the Indian Mound mine 41
29. Map of the Kennedy mine 42
30. Section across a third-order syncline 42
31. Lower part of a typical reverse fault in the Martin mine, Benton, Wis 43
32. Photograph of minor wedge faults in the St. Peter sandstone at Red Rock, Wis 43
33. Map of folds and joints in the north part of the Potosi, Wis., area 43
34. Diagram illustrating the relations of the joint and fold trends in the Potosi, Wis., area 44
35. Diagram showing the vertical joint trends in the Hazel Green-Shullsburg area 44
36. Vertical J_1 tension joint with partly-mined lead-bearing "opening" at Rockville, Wis 45
37. Solution syncline in the Liberty mine 47
38. Highly deformed, solution residue shales of the Guttenberg limestone member in the Graham-Ginte mine 48
39. Coarse block breccia of shalified Guttenberg limestone member in the Graham-Ginte mine 49
40. Section across the steeper north limb of the Mineral Point anticline at the Crow Branch Diggings (S½ sec. 22, T. 5 N., R. 1 W.) 57
41. Geologic mine map and section of the Hoskins mine 59
42. Geologic mine map of the Graham-Ginte mine 60
43. Sections across the Graham-Ginte mine 61
44. A series of diagrams illustrating the progressive structural modes of development of a typical third-order syncline by lateral compressive forces 63
45. A series of diagrammatic sections across the third-order fold shown in figure 58 illustrating the progressive development of the folds and faults by the suggested action of lateral compressive forces 64
46. Early lead furnace 69
47. Lead shot tower at Dubuque, Iowa 70
48. Production of metallic lead, upper Mississippi Valley district 73
49. Production of metallic zinc, upper Mississippi Valley district 76
50. Diagrammatic plans and sections illustrating typical patterns of gash-vein lead deposits and underlying pitch-and-flat zinc deposits 82
51. Large cubic crystals of galena 85
52. Typical banded vein of primary ore 85
53. Acicular crystals of millerite 86
54. Chalcopyrite veinlets in brecciated dolomite 86
55. Reniform crystalline mass of radiating attenuated cubes of pyrite 87
56. Marcasite stalactitic forms from the Monroe mine, New Diggings, Wis 88
57. Smithsonite pseudomorphs of rhombohedral calcite crystals 90
58. Sequence of tectonic events and primary minerals 97
59. Sectional view of a zoned calcite crystal which shows the first 4 sub-stages of calcite deposition as increasingly clearer phantoms 100
60. Deeply colored type 1 calcite crystals, Liberty mine, Meekers, Grove, Wis 101
61. Type 3 calcite crystals in which growth ceased in the later part of the third substage 101
62. Zoned type 4 calcite crystal that shows a marked schalenohedral type 2 crystal within it 102
63. Reverse view of the type 4 crystal shown in figure 62 illustrating typical flat rhombohedral habit and marked transparency 102
64. Guttenberg limestone member and interbedded shale altered by the ore solutions to shaly residues 103
65. Cross section approximately midway between shafts 1 and 2 of Bautsch mine, 5 miles south of Galena, Illinois 104
66. Lime-magnesia-insolubles relations in Guttenberg member 106
67. Pink dolomite vein in gray Ion dolomite member of the Decorah formation, Trego mine, Platteville, Wis 107
68. Slickenside trends of the bedding-plane faults in relation to the folds and ore runs in the Dodgeville mine, Dodgeville, Wis 111
69. Trends of all the slickensides measured on the bedding-plane faults in the Dodgeville mine ore body shown in relation to all the ore-body and fold trends 111
70. Sketch of zigzag slickensides on a bedding-plane fault surface in the Dodgeville No. 1 mine 112
71. Detailed drawing of a typical second-stage ore-bearing fracture zone, South Hayden ore body 116

		Page
FIGURE 72.	Geologic map of the James mine	121
73.	Map of upper Mississippi Valley zinc-lead district showing regional zoning of mineralization	143
74.	Local zones of minerals in the Linden, Wis., subdistrict	144
75.	Maps of Skene, Pittsburg, Betsy, Blewett, North Unity, and Vinegar Hill (zinc) mines and map and section of Royal Princess mine	177
76.	Map of Marsden Black Jack mine	179
77.	Map of Bautsch mine	180
78.	Map of Gray mine	181
79.	Maps of Hughlett and Gray, South Unity, Jefferson, Crawford, and McCabe (or Northwestern) mines	185
80.	Maps of Bull Moose, Middie, Treganza, Frontier, Calvert, Hird No. 1, and New Hoskins mines	192
81.	Maps of Imperial (or Hoover or Iowa), Meloy, Drum, Nightingale, New Ida Blende and Old Ida-Blende mines	195
82.	Maps of Jack of Clubs, Kittoe, Birkett, Byrnes, Monmouth, North Monmouth, Trewartha, and Ollie Bell mines	201
83.	Maps of Sally Waters, Penna-Benton, C. A. T., Blackstone, Champion, and Eureka mines	206
84.	Maps of Lucky Twelve, Fox, Badger, Rowley, and Coughlin (or Murphy) mines	208
85.	Maps of Boyle (or Hardy or Hofer), Little Giant, Galena Level, and De Rocher mines	217
86.	Map of Old Mulcahy mine	222
87.	Maps of Copeland, New Mullen, Booty, Andrews, and Lyne mines	223
88.	Maps of Old Winskell, Thompson, Paquette, and Rodham mines	226
89.	Maps of New Longhorn, Board of Trade, Jarrett, Wicklow, Best, Big Dick, and Connecting Link No. 1 mines	229
90.	Maps of Connecting Link No. 2, Depp (Fever River), Gritty Six, Raisbeck, Big Bill, Trego, Anthony, Dall, and Vandeventer and Blockhouse mines and Cook prospect	235
91.	Maps of Baxter, Coke-Blockhouse, Cruson, Big Jack, Roseleip, and Vinegar Hill Blockhouse mines	240
92.	Maps of Kistler and Stephens, Seitz, East End, Klar-Piquette, Hodge, Grant County, Homestead, Royal, and Acme mines	245
93.	Maps of Enterprise, Empire, Southwestern Wisconsin, M. C., Trego No. 2, Wilson, and Atkinson mines (or Muscalunge Level)	249
94.	Geologic map of Crow Branch mine area	260
95.	Maps of Coker No. 3, M. and A. (or Big Tom), Merry Christmas, Hazel Patch, Western, Gilman, Weigel, Mason, Linden (or Heathcock), Optimo No. 2, and Glanville mines	263
96.	Map of the Okay mine	266
97.	Maps of Optimo No. 3, Optimo No. 4 (or Fearless), South Rule, North Rule, and Prairie mines	276
98.	Maps of North Survey, Dodgeville No. 2, Dodgeville No. 3, Simpson, McKinley-Simpson, and the Dodgeville No. 1 and its adjacent mines	278
99.	Map of Demby-Weist mines	281
100.	Maps of O. P. David, Lampe-Eberle, Clark No. 1, Clark No. 2, Clark No. 3, and Highland mines	284
101.	Map showing mineral deposits in the outlying parts of the district	293

TABLES

		Page
TABLE 1.	Metallic lead production in the upper Mississippi Valley district from 1800 to 1954	74
2.	Metallic zinc production in the upper Mississippi Valley district from 1859 to 1952	77
3.	Copper ore production in the upper Mississippi Valley district	79
4.	Production of iron sulfide concentrates, Wilkinson mine, Cuba City, Wisconsin	80
5.	Iron sulfide concentrate production in the upper Mississippi Valley district from 1899 to 1949	80
6.	Minerals of the Wisconsin, Illinois, Iowa zinc-lead district	84
7.	Chronological list of geologists in respect to the hypotheses they upheld on the origin of the ores	152
8.	Minerals formed by oxidation and redeposition	164

THE GEOLOGY OF THE UPPER MISSISSIPPI VALLEY ZINC-LEAD DISTRICT

By Allen V. Heyl, Jr., Allen F. Agnew, Erwin J. Lyons, Charles H. Behre, Jr.
with special sections by Arthur E. Flint

ABSTRACT

The upper Mississippi Valley zinc-lead district includes the southwest part of Wisconsin, the northwest corner of Illinois, and a narrow fringe of Iowa extending from Bellevue to McGregor, just west of the Mississippi River. The total area of the district is 4,000 square miles. The entire district is drained by the Mississippi River and its tributaries. The central part is a rolling plain dissected to a depth of about 300 feet by the larger stream valleys. Marginal parts of the district are relatively hilly. Most of the district lies within the so-called "Driftless Area", but glacial deposits occur in the eastern, southeastern, and western fringes of the district.

The oldest rocks exposed in this zinc-lead district are the Franconia and Trempealeau formations of Late Cambrian age. These formations crop out along the Wisconsin River. They have a maximum exposed thickness of 215 feet and are overlain with apparent disconformity by the Prairie du Chien group of Early Ordovician age. The Prairie du Chien group is as much as 260 feet thick in some places, but elsewhere it is entirely absent. A disconformity of 1 to 320 feet relief marks the boundary between the Prairie du Chien group and the overlying St. Peter sandstone of Middle Ordovician age. The St. Peter sandstone ranges in thickness from 40 feet to more than 310 feet. Conformably overlying the St. Peter sandstone are about 60 feet of strata of the Platteville formation, also of Middle Ordovician age; these strata can be divided, from bottom to top, into mappable units of sandy shale, dolomite, limestone, and interbedded limestone and dolomite. The top of this formation is marked by a disconformity of less than 5 feet relief. The overlying Decorah formation of Middle Ordovician age, about 40 feet thick, includes three members: a basal green-shale member that thickens towards the northwest, a thin-bedded pinkish-buff sublithographic limestone and interbedded carbonaceous brown-shale member and a medium-bedded gray dolomite or limestone member that has thin greenish-shale partings. The Galena dolomite of Middle Ordovician age, with a thickness of 220 feet, lies conformably upon the Decorah formation; the lower 100 feet of this formation is dolomite containing numerous bands of chert nodules, but the rest of the formation is relatively pure dolomite. The Upper Ordovician is represented by the Maquoketa shale, ranging in thickness from 105 to 160 feet and lying upon the Galena dolomite with apparent conformity. Above the Maquoketa, but probably separated from it by a disconformity, are dolomites of the Edgewood limestone and possibly the Kankakee and Hopkinton limestones, all of Early Silurian age. The Silurian strata crop out along the southern and western edges of the district, and cap a few isolated "mounds" within the zinc-lead area. Rocks of post-Silurian age in the district include Pleistocene glacial and stream deposits, river terraces, loess, boulder deposits, a few small patches of gravels of possible Tertiary age, and fluvial deposits of Recent age. Precambrian igneous rocks have been found only in wells that penetrate the crust to depths of 1,500 to 2,000 feet.

The mining district lies within about 100 miles of the northern edge of Paleozoic sedimentary rocks that overlap the North American Precambrian shield. The Wisconsin arch, a broad northward-trending anticlinal arch, lies east of the area. The Illinois basin lies south of the district, and the Forest City basin lies west and southwest of the district in Iowa.

The regional strike of the sedimentary formations is N. 85° W. throughout most of the district, but it progessively changes to N. 45° W. in the western part. The regional dip is about 17 feet to the mile toward the south-southwest. The rocks of the district are folded into low broad undulations that trend northeastward, eastward, or northwestward.

The larger broad folds range from 20 to 30 miles in length, 3 to 6 miles in width, and 100 to 200 feet in amplitude. Rarely do the folds have dips greater than 15° on their limbs, and commonly the dips are much less than 15°. Generally the north limbs dip more steeply than the south limbs. The smaller folds trend either eastward to northeastward or northwestward. Folds with these two general trends occur throughout the area and form an unusual rhombic pattern.

Most faults in the district are small reverse, bedding-plane, normal, and shear faults. Displacements commonly range from 1 to 10 feet, but some small thrusts on the north limbs of folds have displacements of 25 to 50 feet, and a few shear faults have displacements of from 25 to possibly 1,000 feet.

Many of the ore deposits in the district are localized along small faults—chiefly bedding-plane and reverse faults on the limbs of folds. Bedding-plane faults are present in the incompetent uppermost Platteville and lower Decorah strata. Reverse faults curve upward from these bedding-plane faults, at first at low angles but steepening to about 45° in the overlying competent beds. In general these two types of faults are confined to the flanks of the folds and tend to follow the outline of the folds to form arcuate or linear patterns. Most commonly the reverse faults dip toward the bordering anticlinal areas.

All the rock formations in the district contain well-developed vertical and inclined joints. The vertical joints are traceable for as much as 2 miles horizontally, and for as much as 300 feet vertically. Joints are especially well developed in the Galena dolomite. Most of the vertical joints may be grouped into three average general trends N. 77° W., N. 13° W., and N. 25° E. The joints of the N. 77° W. group are generally more open than those of the other two groups. The inclined joints are commonly tight fractures of local extent, and many of them are probably incipient reverse faults.

Most of the folds, faults, and joints observed in the district are probably a result of a general period of deformation by lateral compression. This deformation was preceded by earlier minor regional deformations. After the main period of deformation some uplift and tilting of the rocks took place.

Regional compressive tectonic forces acting in the north and south and the northeast and southwest directions may have produced the folds, joints, and faults in the district. The folds of the district are similar to drag folds formed on the flanks of basins. The folds lie along the edges of and trend parallel to the rims of the nearby Illinois and Forest City basins. They may have been formed by the differential outward movements of the near-surface Paleozoic strata away from the basins relative to inward movements of the underlying Precambrian basement rocks on the edges of the basins as they were being formed. The lateral compressive forces tended to push the Paleozoic rocks southwest of the Wisconsin arch up the regional dip slope to the north and northeast against the relatively stable area of central Wisconsin. Two forces apparently acted in part simultaneously, producing the arcuate pattern of some of the larger folds and the rhombic cross-pattern of the smaller folds. The folds, faults, and fractured areas were formed early, and sulfide minerals were deposited, probably toward the end of the deformation period, in fractures already formed.

The ore-bearing solutions, possibly mingled with ground water, have dissolved part of the limestone beds of the upper part of the Platteville and the Decorah formations in the local mineralized areas. This solution has caused local thinning of the beds and relaxation by subsidence of the previously formed tectonic structures.

The lead deposits were discovered by the French in the latter part of the 17th century, but mining was restricted mainly to primitive Indian methods until the first American settlers arrived in 1823. The district quickly boomed and it was the principal lead district of the United States until a few years after 1860. Lead production later declined, and in 1954 lead was recovered only as a byproduct. Zinc production commenced in 1859 and reached its maximum activity during the First World War. A revival of mining about 1938 by small companies continued until shortly after the Second World War. Since then a few larger companies have developed ample reserves by prospecting, and mining on a large scale has been renewed. In 1945 the production was worth about $3,000,000 of ore. The total lead production from 1798 to 1947 was 814,339 short tons of lead metal. The recorded zinc production from 1859 to 1947 is 1,005,476 short tons of zinc metal from 38,000,000 short tons of ore. The ores, which are relatively low grade, contain 4 to 8 percent zinc and 0.5 to 1 percent lead. The volume of the average ore body discovered from the beginning of 1915 to 1954 was between 100,000 and 500,000 short tons of ore, with a few ore bodies containing as much as 3,000,000 tons. Successful mining of the ores depends in part upon the efficient handling and treatment of the materials and in part upon the nearness of the deposits to the smelters. Road material, agricultural limestone, iron sulfides, barite, and copper have been byproducts or minor products of the mining.

The principal primary minerals of the deposits are quartz (chert and other forms of cryptocrystalline silica), dolomite, sphalerite, marcasite, pyrite, galena, barite, calcite, and chalcopyrite. Secondary minerals include smithsonite, limonite, and cerussite. The primary minerals are deposited in a regular paragenetic sequence throughout the district in the order listed.

The host rocks within and in the immediate vicinity of the deposits were altered by several processes: (1) silicification, (2) dolomitization, and (3) solution of calcareous rocks.

The ore bodies can be classified into three main types: (1) reverse-fault- and fold-controlled ore bodies, (2) joint-controlled ore bodies, and (3) placer and residual deposits. The ore deposits of the first type are in systems of reverse and bedding-plane faults that are better developed in the southern part of the district. The ore bodies are found on the flanks and curved around the ends of anticlines or synclines, but ore bodies around the ends of synclines are more common. The ores in the reverse-fault and fold deposits are deposited as (1) vein fillings along fractures and bedding planes; (2) cavity fillings in solution breccias; and (3) disseminations by replacement and impregnation in favorable beds, particularly in shaly strata. The most abundant ore mineral of the joint-controlled deposits is galena, which is in veins filling vertical joints and in podlike deposits in favorable beds crossed by these joints. Placer and residual deposits along stream valleys are small and are mainly useful for locating ore deposits in the bedrock.

Deposits of sulfides have been found in all the geologic formations exposed within the mineralized part of the district. The commercial zinc and lead deposits, however, are in the Platteville and Decorah formations and the Galena dolomite, except for a few in the Prairie du Chien group. Most of the zinc deposits are in the upper Platteville formation, the Decorah formation, and the lower part of the Galena dolomite, whereas most of the joint-controlled lead deposits are in the Galena.

Nearly all the zinc ore bodies, although controlled in detail by local small folds, lie within the larger synclines and are along definite trends, the most important of which are northeasterly, easterly, and southeasterly. Some of these ore-body trends are traceable for miles.

The ore deposits show both a horizontal and a vertical zoning. A central horizontal zone, marked by an increase in copper, barium, nickel, and lead in the ores, passes northwestward through the east-central part of the district, irrespective of structure. The vertical zoning is marked by greater concentrations of galena near the present surface, but zinc, iron, nickel, silica, and possibly magnesium and copper in the deeper deposits are relatively abundant.

The evidence suggests that the ores were deposited from rising low-temperature hydrothermal solutions ("telethermal") having a magmatic source. However, much of the evidence applies equally well to a cold-artesian-water hypothesis and some even to a cold-descending-meteoric-water hypothesis.

INTRODUCTION

GENERAL FEATURES OF THE REGION

LOCATION

The upper Mississippi Valley zinc-lead district, comprising an area of about 4,000 square miles, includes the southwest part of Wisconsin, the northwest corner of Illinois, and a narrow fringe of the northeast edge of Iowa along the west bank of the Mississippi River. (See pl. 1.) Lead and zinc deposits occur throughout the entire area, but recent production of ore has been limited to about 650 square miles in a belt extending north and south through the central part of the district. Discoveries of ore bodies since 1942 have considerably enlarged this productive area. (See pl. 1.) Small isolated deposits of lead, copper, and zinc are on all sides of the main district, indicating that the total area of mineralization is considerably larger than the actual mining district.

Not all the territory outlined as the mining district (pl. 1) contains commercial deposits of lead and zinc. Within its limits, particularly near the fringes, are small areas that are barren, so far as known, and others show only scattered mineralization.

CLIMATE AND VEGETATION

The climate of the district is cool temperate; heavy snows and considerable periods of subzero temperatures characterize many of the winters. The inclement weather during these cold periods sometimes interferes with mining and prospecting. The average winter temperature is between 20° and 30° F. and the average summer temperature is between 65° and 75° F. The first frost is generally late in September; the last one is early in May. The annual precipitation of about 25 to 30 inches is fairly evenly distributed throughout the year.

Prior to settlement the district was about three-fourths mixed deciduous forest and one-fourth prairie. The areas of prairie were essentially limited to the nearly level land along the main drainage divides. Most of the original prairie land is now being cultivated, including a large part of the best farm land in the district, but some is retained as pasture.

GENERAL GEOGRAPHY

Except for its east and west borders, the district lies entirely within the southern part of the well-known Driftless Area.

The topography is relatively rugged as compared with most of the region surrounding the Driftless Area. The dominant topographic feature is an upland that is about 900 feet in altitude in the southern part of the district and rises gently toward the north to 1,250 feet near Highland, Wis. The local relief normally ranges between 100 and 300 feet, but the maximum relief is 1,100 feet, in part resulting from a number of low escarpments and isolated hills or mounds that rise above the general level of the gently rolling upland. These mounds, which are prominent features of the landscape northeast of the main escarpment in Illinois and Iowa, rise about 200 feet above the general level of the upland. The principal mounds are Sinsinawa Mound at Fairplay, Wis.; the three Platte Mounds between Platteville and Belmont, Wis.; and the two Blue Mounds at Blue Mounds, Wis. The highest of these mounds, the west Blue Mound, has an altitude of a little more than 1,700 feet. The east and west fringes of the district were glaciated and therefore show topography typical of areas formerly covered by continental glaciers.

A generally dendritic network of streams, all tributary to the Mississippi River, drain the area and occupy shallow valleys which are more deeply incised near the master stream. The Mississippi River flows in a cliff-walled valley incised 200 to 300 feet into the adjoining upland. The major tributaries of the Mississippi River from the east are the Wisconsin River, which essentially bounds the district on the north, and proceeding southward down stream, the Grant River, Platte River, Sinsinawa River, Galena (Fever) River, and Apple River. The several branches of the Pecatonica and Sugar Rivers drain the eastern part of the district into the Rock River, which in turn flows into the Mississippi. The major tributaries flowing into the Mississippi River from the west are—from north to south—the Turkey River, the Little Maquoketa River, Catfish Creek, and the Tete des Morts River.

CULTURAL DEVELOPMENT AND FACILITIES RELATED TO MINING

The principal city in the district, Dubuque, Iowa, has a population of about 50,000. Other towns of importance, Monroe, Wis.; Platteville, Wis.; and Galena, Ill.; each have a population of 5,000.

The district is served by the Illinois Central, the Chicago, Burlington, and Quincy, the Chicago Great Western, the Chicago, Milwaukee, St. Paul, and Pacific, and the Chicago and Northwestern Railroads.

The area is accessible by many paved highways connecting the principal towns, and bus and truck lines serve all the larger towns. Secondary roads in the Wisconsin part of the area are all kept in excellent condition by the use of mine tailings.

Economical transportation is available on the Mississippi River. Dubuque, Iowa, is the chief port, with Prairie du Chien, Wis., the second most important. Galena, Ill., formerly the principal port of the area, is no longer used, as the lower reaches of the Galena (Fever) River have not been navigable since about 1915.

Two zinc smelters, the DePue smelter of the New Jersey Zinc Co. and the Matthiessen and Hegeler smelter, both located near LaSalle, Ill., are within 150 miles of the district. A third plant, Hegeler Brothers smelter at Danville, Ill., is 300 miles southeast of the upper Mississippi Valley district. The American Zinc Co. smelter, at East St. Louis, Ill., is 400 miles to the south. The nearness of the district to smelters and the consequent low transportation costs are a distinct advantage for this area in comparison with some other zinc districts in the United States.

FIELD WORK AND ACKNOWLEDGMENTS

The geological study of the Wisconsin-Illinois-Iowa zinc-lead district was begun by the U. S. Geological

Survey in October 1942, and was still in progress in 1957.

The initial investigation was an analysis of the structural control of the ore deposits in an area of numerous open mine workings and drill holes, and some exposures, and included a cooperative prospecting program with the U. S. Bureau of Mines. This study was soon extended and expanded by the U. S. Geological Survey to a general geologic mapping program of the mining district, including the areal geology, stratigraphy, structure, and economic geology and the larger geologic features. The investigation has continued without interruption since 1942.

This report is based on field work begun in October, 1942 and completed in July, 1950. Separate comprehensive reports on the stratigraphy (Agnew, Heyl, Behre, and Lyons, 1956) and the mineral resources (Heyl, Lyons, Agnew, and Behre, 1955) have been prepared.

A. F. Agnew was in charge of the party from 1942 until December 1945; A. V. Heyl, Jr., was in charge from January 1945 to 1950, except for a part of 1948-49 when E. J. Lyons was in charge. C. H. Behre, Jr., was party advisor from 1942 to October 1945.

The members of the field party consisted of A. F. Agnew, from October 1942 to December 1945 and also during the summer of 1948 and from June 1949 to August 1950; A. V. Heyl, Jr., from February 1943 to July 1950; E. J. Lyons, from February 1944 to June 1948 as a part-time member of the party and as a full-time member of the party from June 1948 to October 1949; and C. H. Behre, Jr., as a part-time member from October 1942 to October 1945. A. E. Flint, J. J. Theiler, C. W. Tandy, R. P. Crumpton, Dorothy J. West, J. C. Spradling, D. C. Dixon, and R. M. Hutchinson also assisted with the field work for various periods of time.

Part-time assistance by students of the Wisconsin Institute of Technology greatly expedited both the field work and the completion of this report. The following students contributed a part of their time: J. H. Moor, J. F. Coulthard, Maxine L. Heyl, Harriette A. Burris, D. W. Russmeyer, Catherine M. Fulkerth, and H. F. Seeley.

Helen C. Cannon, H. E. Hawkes, L. C. Huff, and V. C. Kennedy, of the U. S. Geological Survey, spent parts of several field seasons in geochemical prospecting research in the district.

The work in the field was greatly aided by the excellent cooperation of the Wisconsin Geological and Natural History Survey, directed by E. F. Bean, which contributed to the funds required to continue the work from July 1945 to July 1950, supplied a large amount of valuable data, and made many pertinent suggestions concerning the planning of the study. F. T. Thwaites of the Wisconsin Survey contributed suggestions and drill-hole logs of the deeper wells in the area. The Illinois State Geological Survey had a party in the field with an office at Galena, Ill., during the summer of 1943 and from the spring of 1944 until July 1950. During those years field parties including Paul Herbert, Jr., H. B. Willman, R. R. Reynolds, C. A. Bays, J. E. Bradbury, R. M. Grogan, and R. C. McDonald studied the geology of the Illinois part of the district, and work was greatly aided by a free interchange of mining records and geological information. H. B. Willman and R. R. Reynolds contributed photographs and their data on lead mines in Illinois. A. C. Trowbridge and H. G. Hershey, state geologists of Iowa, freely contributed information on the Iowa part of the district. Furthermore, their assistance in the geologic mapping of the Center Grove-Pikes Peak area in Iowa is gratefully acknowledged. J. R. Ball, professor of Geology at Northwestern University; E. N. Cameron, professor of Geology at the University of Wisconsin; and Mohammed Vallialah, of the Indian Geological Survey, contributed to our understanding of the geology of the district.

The U. S. Bureau of Mines maintained a party in the district from December 1943 to July 1949, except for a few months in 1946. This program was in official cooperation with the United States Geological Survey until 1946. We wish to acknowledge not only their invaluable aid in carrying out our studies but also the freely given samples and the records and other data that greatly assisted in the study of the ore bodies and the subsurface geology. The Bureau of Mines engineers who conducted the program are G. A. Apell, P. M. Zinner, H. B. Ewoldt, F. C. Lincoln, O. W. Terry, James V. Kelly, W. A. Grosch, S. P. Holt, E. F. Fitzhugh, Jr., A. J. Martin, H. W. Davis, M. H. Berliner, Margaret Lickes and A. M. Cummings.

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A. F. Agnew wrote most of the stratigraphic section of this report, and Arthur E. Flint wrote the sections on the Pleistocene and the physiography as special contributions. A. V. Heyl, Jr., is responsible for the writing of most of the remainder of the report, except for the section on exploration and mining, which was written jointly with E. J. Lyons, and for several mine descriptions that were written by A. F. Agnew and C. H. Behre, Jr. The stratigraphic work was done mainly by A. F. Agnew, with A. V. Heyl, Jr., Erwin J. Lyons, and C. H. Behre, Jr., assisting; and the work on structure and ore deposits was mainly done by A. V. Heyl, Jr., with a large amount of assistance from A. F. Agnew, E. J. Lyons, C. H. Behre, Jr., A. E. Flint, J. J. Theiler, J. H. Moor, and C. W. Tandy. H. G. Hershey, of the Iowa Geological Survey, and M. H. Berliner, of the U. S. Bureau of Mines, helped map the geology of the Pikes Peak-Center Grove area. R. R. Reynolds, geologist for Calumet and Hecla, provided structural data for a large area near Shullsburg, Wis. The men who are responsible for the mapping are credited on the individual maps.

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SCOPE OF THE REPORT

The study of the upper Mississippi Valley district was undertaken primarily as an investigation of the zinc and lead ore deposits.

The present general report on the district includes detailed descriptions of the areal geology of several selected areas (pls. 2, 3, 4, 5, 6, 7); a description of the stratigraphy of the principal ore-bearing beds; a description of general structural relations and the detailed structures of the ore bodies; a description of the ore deposits, including their history, production, general mineralogy, relation to the larger geologic features, vertical and horizontal zonation, and origin; a discussion of some geologic principles applied to exploration and mining; and descriptions of the more important mines. The report is based essentially on a field study, which ended in 1950, since then studies have been continued by other geologists, whose work is being published in separate reports. As far as possible the production data, history, mine descriptions and references have been kept up to date (to July 1957) in order that the report is more useful to the reader.

PREVIOUS GEOLOGIC WORK IN THE DISTRICT

Geologic studies in the upper Mississippi Valley zinc-lead district were begun early in the nineteenth century, and many geologists have investigated various aspects of the geology.

The earliest work of any consequence was performed in 1839 by David Dale Owen (1840), who made a general reconnaissance of the district, mapped the location of the lead mines, and described the general geology. He recognized the presence of the "Lower sandstone" (Cambrian), the "Lower Magnesium" dolomite (Prairie du Chien), the "Upper sandstone" (St. Peter), the "Blue limestone" (Platteville and lower Decorah), and the "Cliff limestone" (upper Decorah and Galena). However, he confused the dolomities of Silurian age with the Galena, and completely missed the Maquoketa shale because of its poor outcrops. Nevertheless, he laid the foundation for work by later geologists. Owen was followed by Edward Daniels in 1854, and J. G. Percival in 1855–1856 (reports full of still pertinent details); J. D. Whitney and James Hall in 1858, 1862 and again Whitney in 1866, the first detailed reports covering the entire district; James Shaw in 1873 (Illinois); the valuable report of Moses Strong in 1877 (Wisconsin); the careful, excellent report of T. C. Chamberlin in 1882 covering all of southern Wisconsin; W. P. Blake, W. P. Jenney, and Arthur Winslow (all in 1893–94); by A. G. Leonard in 1897 (Iowa), Samuel Calvin and H. F. Bain in 1900 (Iowa), and by C. R. Van Hise and H. F. Bain in 1902. About this time the need for more detailed studies of the geology of the district was recognized, resulting in the careful reports and maps by U. S. Grant in 1903 and 1906, H. F. Bain in 1905 and 1906, Grant and E. F. Burchard in 1907, G. H. Cox in 1914, Hotchkiss and others in 1909 and 1914, and E. W. Shaw and A. C. Trowbridge in 1916. More recent studies on phases of the geology of the district include publications by H. C. George (1918), W. F. Boericke and T. H. Garnett (1919), J. E. Spurr (1924), G. M. Kay in 1928, 1929, and 1935, W. H. Emmons (1929), C. K. Leith (1932), W. H. Newhouse (1933), A. F. Banfield (1933), E. R. Scott (1934), G. I. Atwater (1935), L. C. Graton and G. A. Harcourt (1935), C. H. Behre, Jr. (1935), Behre, Scott, and Banfield in 1937, E. S. Bastin, Behre, and G. M. Kay (1939), R. M. Garrels (1941), H. B. Willman, R. R. Reynolds and Paul Herbert, Jr. (1946).

GEOLOGY

STRATIGRAPHY

The district contains sedimentary rocks that range in age from Late Cambrian to Early Silurian. Unconsolidated sediments of Pleistocene age, related to glaciation locally overlie these rocks, particularly in the fringes of the district. No igneous and metamorphic rocks are exposed, although Precambrian rocks of these origins exist below the base of the gently folded Paleozoic strata (as shown by deep drill holes). Precambrian rocks crop out north and northeast of the zinc-lead district.

The total thickness of the Paleozoic strata is about 1,800 feet, of which 800 feet is Cambrian, 780 feet is Ordovician, and 200 feet is Silurian. The dominant rock of the Cambrian strata is sandstone; the Ordovician rocks include dolomite, shale, sandstone, and limestone, in the order of decreasing abundance; the beds of Silurian age consist of shaly and cherty dolomite.

The bedrock exposed in the zinc-lead district consists chiefly of rocks of Ordovician age, but dolomite of Early Silurian age cap a few of the higher hills in Wisconsin, and form the large areas of uplands farther south and west, in the northwestern part of Illinois and the northeastern part of Iowa. Beds of Cambrian age are exposed only along the northern fringe of the district, in the bluffs of the Wisconsin River and in the ravines that border it (fig. 1).

This brief description of the rocks of the mining district is concerned primarily with the relationship of the strata to the ore deposits. Therefore, the characteristics of the rock units for the general area are briefly presented, and specific features of the rocks that have affected the localization of the ore are discussed in greater detail. A more complete description of the rock units and a thorough discussion of their stratigraphic relationships has been published (Agnew, Heyl, and others, 1956).

The stratigraphic information presented is that known on July 1, 1950, except for the citations to literature that mention significant contributions since then.

PRECAMBRIAN ROCKS

Precambrian rocks were reported [1] in a well at Platteville, Wis. (city well 2, sec. 15, T. 3 N., R. 1 W.), where the drill penetrated "granite" at a depth of 1,714 feet. Wells at the north margin of the district, in Richland Center, Wis. (sec. 16, T. 10 N., R. 1 E.), penetrated similar Precambrian rocks at depths ranging from 665 to 678 [2] (fig. 1, locality 1). In the Baraboo area, just northeast of the zinc-lead district, and in northern Wisconsin the Precambrian rocks are separated from the overlying Cambrian sedimentary rocks by ar unconformity of considerable relief.

CAMBRIAN SYSTEM

UPPER CAMBRIAN SERIES

The oldest rocks of Paleozoic age found in the upper Mississippi Valley are sandstone, siltstone, and dolomite, of Late Cambrian age (fig. 2). These beds are exposed only along the northern and northeastern edges of the zinc-lead district and are encountered farther south in deep wells drilled for water and as oil tests. An excellent exposure of much of the upper 150 feet of Cambrian strata is seen in the bluff at the highway intersection 2 miles north of Boscobel, Wis., sec. 22, T. 8 N., R. 3 W. (fig. 1, locality 2).

The thickness of the Cambrian strata increases southward from about 1,000 feet at the north fringe of the district (fig. 1, localities 2 and 3),[3] to 1,284 feet at Platteville.

The earliest beds of Cambrian age in the mining district are termed the Mount Simon sandstone. The southward increase in thickness of the Cambrian sequence is due mainly to this formation, which ranges from 442 feet thick at Boscobel to 778 feet at Platteville.

The Mount Simon is overlain by the Eau Claire sandstone, which is normally very silty and reddish. Its thickness is between 70 and 330 feet. This forma-

[1] Data in files of Wisconsin Geological and Natural History Survey, Madison, Wis.

[2] Data in files of Wisconsin Geological and Natural History Survey, Madison, Wis.

[3] Borden Co. Whey Plant well 2, Boscobel, Wis., sec. 33, T. 8 N., R. 3 W. (fig. 1, locality 3). Data in files of Wisconsin Geological and Natural History Survey, Madison, Wis.

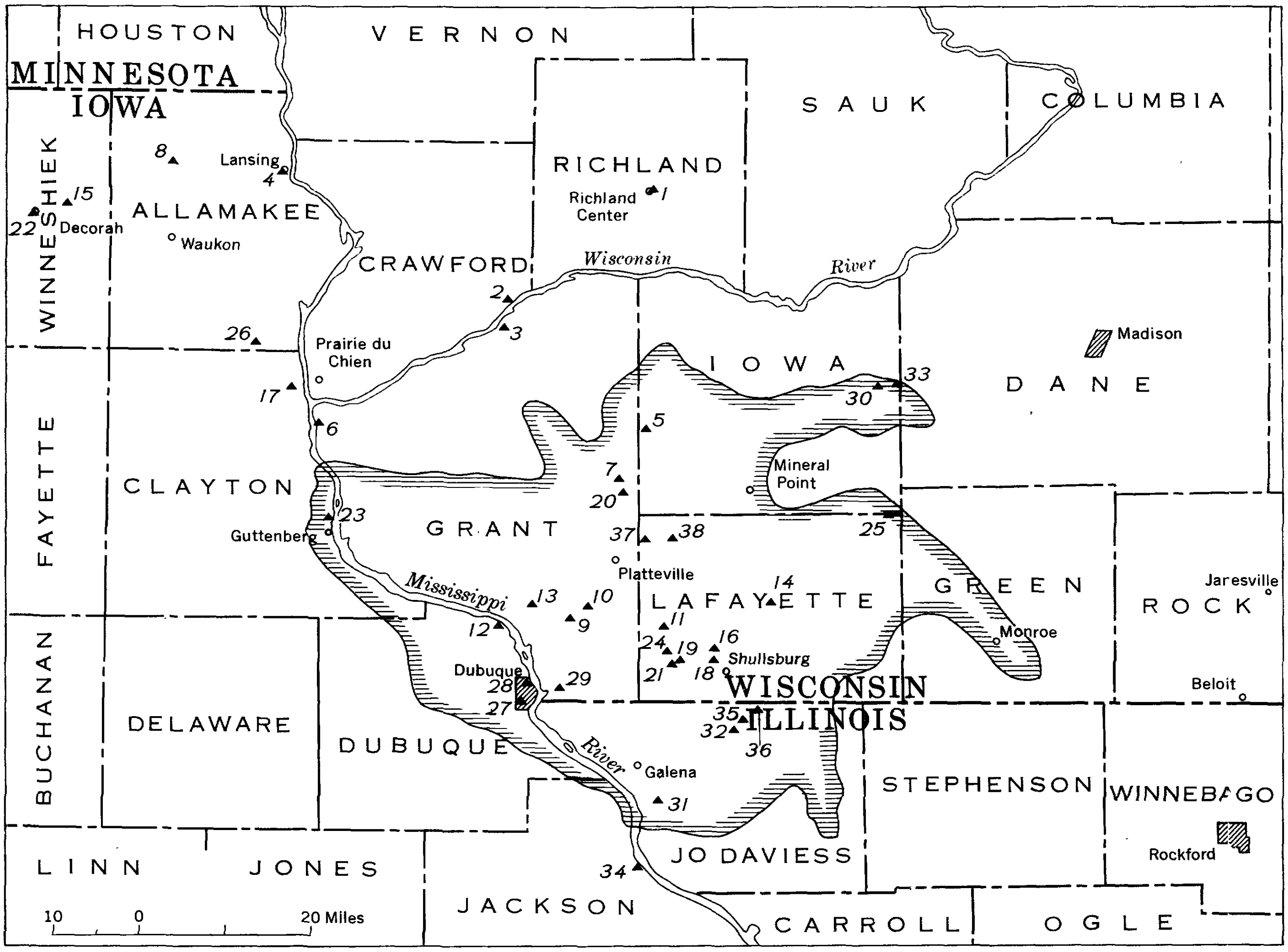


FIGURE 1.—Index map showing outline of principal mineralized area and stratigraphic locations cited in text.

tion is overlain by the Dresbach sandstone which ranges from 62 to 140 feet thick.

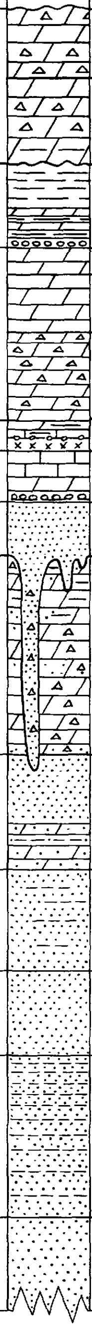
Above the Dresbach sandstone is the Franconia sandstone which is between 110 and 140 feet thick. The glauconite in the Franconia is the principal means by which it can be distinguished from the similar overlying and underlying sandstones.

The Trempealeau formation, which overlies the Franconia sandstone, is principally sandstone and siltstone, although commonly the lower strata are dolomite. The uppermost beds of Trempealeau formation are called the Jordan sandstone member, which is composed of clean well-sorted coarse quartz grains that are subangular to round. The Trempealeau formation averages 120 to 150 feet in thickness.

In places in the mining district and along its fringes a unit called the Madison sandstone overlies the Jordan sandstone member of the Trempealeau formation. Raasch regards the Madison sandstone as a separate formation, basing this opinion primarily upon sedimentary and lithologic criteria, which Twenhofel and Thwaites (Twenhofel, Raasch and Thwaites, 1935, p. 1711, footnote 45) consider as having little weight. He describes the Madison as a poorly sorted silty or conglomeratic quartz sandstone as much as 60 feet in thickness. It is not consistently recognizable in the mining district.

In most places beds transitional in lithologic character fill the interval between the Jordan sandstone member and the overlying Oneota dolomite of the Prairie du Chien group (see also Schuldt, 1943, p. 404). These transitional beds, which consist of alternating dolomitic sandstones and arenaceous dolomites, aggregate as much as 27 feet in thickness.

Lead minerals are found in Cambrian rocks in a mine (fig. 1, locality 4) near Lansing, Iowa, sec. 10, T. 99 N., R. 4 W. (Calvin, 1894, p. 106–107; Leonard, 1897, p. 56); and 35 miles to the north, at Dresbach, Minn., sec. 18, T. 105 N., R. 4 W. (Emmons, 1929, p. 265–266; Winchell, 1884, p. 258–259). Both localities are mar-



System	Series	Group or formation	Description	Average thickness, in feet	
SILURIAN	Middle and Lower		Dolomite, buff, cherty; *Pentamerus* at top,	90	200
			Dolomite, buff, cherty; argillaceous near base	110	
ORDOVICIAN	Upper	Maquoketa shale	Shale, blue, dolomitic; phosphatic depauperate fauna at base	108–240	
	Middle	Galena dolomite	Dolomite, yellowish-buff, thin-bedded, shaly	40	225
			Dolomite, yellowish-buff, thick-bedded; *Receptaculites* in middle	80	
			Dolomite, drab to buff; cherty; *Receptaculites* near base	105	
		Decorah formation	Dolomite, limestone, and shale, green and brown; phosphatic nodules and bentonite near base	35–40	
		Platteville formation	Limestone and dolomite, brown and grayish; green, sandy shale and phosphatic nodules at base	55–75	
		St. Peter sandstone	Sandstone, quartz, coarse, rounded	40+	280–320
		DISCONFORMITY	DISCONFORMITY		
	Lower	Prairie du Chien group (undifferentiated)	Dolomite, light-buff, cherty; sandy near base and in upper part; shaly in upper part	0–240	
CAMBRIAN	Upper	Trempealeau formation	Sandstone, siltstone, and dolomite	120–150	
		Franconia sandstone	Sandstone and siltstone, glauconitic	110–140	
		Dresbach sandstone	Sandstone	60–140	700–1050
		Eau Claire sandstone	Siltstone and sandstone	70–330	
		Mount Simon sandstone	Sandstone	440–780	

FIGURE 2.—Generalized stratigraphic column for zinc-lead district.

ginal to the mining district. (See fig. 9.) The Lansing occurrence is in the uppermost beds of the Cambrian, probably the dolomitic transition beds, whereas in the Minnesota locality the minerals were found in a shale 350 to 400 feet below the top of the Cambrian, probably in the lower part of the Dresbach sandstone.

Sphalerite was recognized in cuttings from USGS-Leix drill hole 1 near Montfort, Wis., sec. 30, T. 6 N., R. 1 E. (Heyl, Lyons, and Agnew, 1951, p. 9), from 149 to 159 feet below the top of the Cambrian beds in dolomitic sandstone identified as Franconia (fig. 1, locality 5). The same cuttings assayed between 0.05 and 0.1 percent zinc, and between 2 and 3 percent iron in the form of pyrite, and cuttings taken from 141 to 179 feet below the top of Cambrian rocks were estimated to contain 1 to 3 percent iron.

Iron desposits in Cambrian rocks are abundant, especially just north of the zinc-lead district (Strong, 1882, p. 49–56; Chamberlain, 1882, p. 518–520).

Water supplies ample for large industrial plants and municipalities are obtained from the Cambrian strata, especially from the Dresbach sandstone.

ORDOVICIAN SYSTEM

LOWER ORDOVICIAN SERIES

PRAIRIE DU CHIEN GROUP

The Prairie du Chien group was named by Bain (1906, p. 18) from exposures near Prairie du Chien, Crawford County, Wis., but is commonly known in the upper Mississippi Valley by the old name of Lower Magnesian Limestone of Owen (1843, fig. 1). It lies above the beds of Cambrian age along the north fringe of the mining district and in the more deeply incised areas in the central part of the district. Perhaps the most nearly complete exposure is in the quarry at the north edge of Wyalusing, Wis., sec. 31, T. 6 N., R. 6 W., and sec. 36, T. 6 N., R. 7 W. (fig. 1, locality 6).

The strata of the Prairie du Chien group range widely in lithologic character. In places the group is divisible into three units: the Oneota dolomite, which overlies the Cambrian beds; the New Richmond sandstone; and the Shakopee dolomite.[4] In other places, however, no recognizable sandstone unit is found; thus, no threefold division can be made. Furthermore, beds that occupy the interval represented by the Prairie du Chien group are locally sandstone, red shale, green shale, silicified limestone, and limestone.[5]

The dolomite of the Prairie du Chien group is light buff to light gray, finely to medium crystalline, in part vuggy, and thin to thick bedded. It is commonly oolitic, sandy with clear rounded quartz grains, and cherty. Locally, the dolomite has been silicified, especially where evidence of iron-zinc-lead mineralization is abundant. Thin green glauconitic shale lentils are found along bedding planes and in the dolomite. Mound-shaped *Cryptozoon* individuals are common in certain strata. The sandstone is similar to that in the Cambrian beds below, and commonly has lenses and beds of green glauconitic shale. The sandstone in most places has dolomitic cement.

The Prairie du Chien group attains a maximum thickness of about 250 feet; this group and the overlying St. Peter sandstone, from which it is separated by an unconformity, have an aggregate thickness of 280 to 320 feet in the zinc-lead district.

The Prairie du Chien group constitutes one of the potential mining zones in the zinc-lead district. Although this potential productive zone has not been widely prospected as yet, evidences of old lead-mining activity (Calvin, 1894, p. 103–107; Leonard, 1897, p. 53–56; Jenney, 1894, p. 211–212, 644; Percival, 1855, p. 66; Percival, 1856, p. 59, 63; Whitney, 1862, p. 408–413; Chamberlin, 1882, p. 511–517, 554–560; Daniels, 1854, p. 24) in these beds coupled with recent testing (Heyl, Lyons, and Agnew, 1951; Agnew, Flint, and Allingham, 1953, p. 7–11) show that, with more favorable economic conditions, these strata might become a lower producing zone and thus prolong the life of the district. Lead mining in the Prairie du Chien group has been restricted to areas of its exposures along the north fringe of the district. The drilling by the U. S. Geological Survey, 1949–51, confirmed the presence of zinc and iron minerals in these beds in Wisconsin, at the Crow Branch diggings, sec. 21, T. 5 N., R. 1 W. (fig. 1, locality 7), and as far south as Cuba City. Zinc minerals have been found elsewhere in these beds, but not in any great abundance, except north of Waukon, Iowa, at the Mineral Creek lead mines, sec. 13, T. 99 N., R. 6 W. (fig. 1, locality 8), where both zinc and lead were mined, and at the Denby-Weist mines (fig. 99).

MIDDLE ORDOVICIAN SERIES

ST. PETER SANDSTONE

The St. Peter sandstone, named by Owen (1847, p. 170) for exposures along the St. Peters (now Minnesota) River, near St. Paul, Minn., is exposed along the Wisconsin River and its tributaries, along the Mississippi River southward almost to Dubuque, Iowa, and in areas of deep dissection within the zinc-lead district. There are good exposures along U. S. Highway 151 in Wisconsin, in sec. 12 at Hoadley Hill and in sec. 15, T. 2 N., R. 2 W. (fig. 1, localities 9 and 10).

The St. Peter sandstone consists of clear fine to coarse subangular to round quartz grains. As a rule the sandstone is poorly cemented; where the rock is indurated, the cement is dolomitic, calcareous, or siliceous. Greenish argillaceous binding material is present especially in the upper few feet of the unit and near its base, particularly where the sandstone is abnormally thick; otherwise, the sandstone is relatively clean. The sandstone is thin bedded to massive; crossbedding is characteristic. In many places iron oxide cements give the St. Peter sandstone a variety of colors, brown and red being the most common.

The St. Peter sandstone averages 40 feet in thickness. However, the St. Peter sandstone was penetrated in

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[4] The name Root Valley has been applied to a standstone at the New Richmond horizon (Stauffer and Thiel, 1941, p. 59). The name Willow River is used by many in place of Shakopee (Powers, 1935, p. 390).

[5] These strata have been assigned to the basal part of the St. Peter sandstone (Heyl, Lyons, Agnew, 1951, p. 5).

USGS-Raisbeck drill hole 2, sec. 22, T. 2 N., R. 1 E. at Meekers Grove, Wis. (fig. 1, locality 11), for a thickness of at least 320 feet (Heyl, Lyons, and Agnew, 1951, p. 11–12). Near Shullsburg green and red shales are present interbedded with the sandstone. This variation of St. Peter sandstone is known to be more than 300 feet thick (city well 3, Shullsburg, Wis., sec. 10, T. 1 N., R. 2 E.; [6] see also p. 9). At least part of the variation in thickness is due to an unconformity at the base of the St. Peter sandstone, which is well exposed in the glass-sand quarry south of Clayton, Iowa, sec. 1, T. 93 N., R. 3 W., directly across the Mississippi River from the Wyalusing quarry (fig. 1, locality 6).

Lead and zinc minerals are uncommon in the St. Peter sandstone. Small amounts have been found where mineralized fractures connect with mineralized areas in higher beds, as at Mineral Point (Percival, 1855, p. 55) and at Crow Branch, Wis., sec. 21, T. 5 N., R. 1 W. (Whitney, 1862, p. 363), shown on fig. 1, locality 7. Iron minerals are abundant locally in the St. Peter, especially in the uppermost few feet, where pyrite cements the quartz-sand grains. This iron-sulfide mineralization appears to be more abundant in local areas that have zinc-lead deposits in overlying beds and in larger areas where the iron minerals appear to be related to major structural features, as at Red Rock, Wis. (sec. 17, T. 2 N., R. 4 E.), 10 miles northeast of Shullsburg.

In most places the St. Peter sandstone provides an ample supply of water for small towns, for small industrial plants, and for farms.

PLATTEVILLE FORMATION

The Platteville formation, named by Bain (1905, p. 19) from exposures near Platteville, Wis., is known throughout the mining district by exposures at the surface and in mines, and by cuttings from wells and prospect drill holes. Exposures are numerous; however some of the best outcrops of the Platteville can be seen in the quarry at Spechts Ferry Station, Iowa, sec. 4, T. 90 N., R. 2 E. (fig. 1, locality 12; along U. S. Highway 151 at Hoadley Hill northeast of Dickeyville, Wis., sec. 12, T. 2 N., R. 2 W. (locality 10); along U. S. Highway 61 northwest of Dickeyville, sec. 7, T. 2 N., R. 2 W. (locality 13; and in the quarry at Darlington, Wis., sec. 3, T. 2 N., R. 3 E. (locality 14).

The Platteville formation consists of the following four members in descending order (fig. 3):

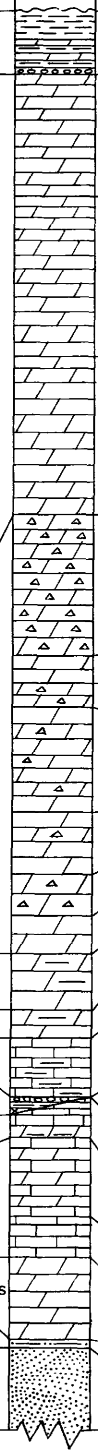
Quimbys Mill member (limestone and dolomite).
McGregor limestone member (in part dolomite).
Pecatonica dolomite member.
Glenwood shale member.

[6] Data in files of Wisconsin Geological and Natural History Survey, Madison, Wis.

The Platteville formation ranges in thickness from 55 feet in the western part (Heyl, Lyons, and Theiler, 1952) of the district to 75 feet near Shullsburg. Wis.

An excellent exposure of the lower three members of the Platteville formation in the western part of the mining district is in the long roadcut along U. S. Highway 151, at Hoadley Hill about 8 miles southwest of Platteville, Wis, NW¼NE¼ sec. 12, T. 2 N., R. 2 W. (fig. 1, locality 9; fig. 4). This section, here designated the typical Platteville section, appears as follows:

	Thickness (feet)
Decorah formation:	
Spechts Ferry shale member (clay bed, in part slumped):	
Shale, bluish green	0.5+
Bentonite; white, weathering orange brown	.2
Shale, yellowish green above to bluish green below	.2
Shale, brown and olive, soft	.1
Platteville formation:	
Quimbys Mill member (glass rock):	
Limestone, dark purple, fine-grained, dense, conchoidal fracture; very wavy upper surface; thin dark-brown to black, fossiliferous, platy shale parting at base	0.3–.5
McGregor limestone member (Trenton of local usage):	
Limestone, light gray, very fine-grained, very dense; conchoidal fracture like "glass rock" above, fairly massive; very fossiliferous; wavy upper surface	.9
Limestone like next above but less dense; medium bedded above to thin bedded below; fossiliferous; wavy upper surface	.7
Dolomite, light-olive-drab, finely granular, argillaceous; very thin bedded; wavy bedded	1.6
Dolomite like next above but heavy bedded; calcite near middle	3.0
Limestone; thin bedded yet stands massively as one unit; light greenish grayish brown, weathering brown; with a few argillaceous streaks; sparingly fossiliferous, but with fossils and fucoids on top surface	2.6
Limestone; thin bedded like next above but the beds are distinct; wavy beds and shaly partings; argillaceous in upper 0.3 foot, which is very fossiliferous	3.4
Limestone, light-buffish-gray; in medium to heavy beds; in places gradational into unit next below	3.6
Total upper McGregor	15.8
McGregor limestone member (Mifflin beds of Bays, 1938):	
Limestone, light-greenish-gray to bluish-gray; in massive beds but composed of thin beds which are not separated; much shaly material in wavy bands; fairly fossiliferous, argillaceous: a peculiar mottled light-gray and darker gray 0.1-foot zone, 1 foot below top	3.9



Formation	Member and subdivision			Local terminology	Description	Unaltered thickness, in feet		
Maquoketa				Shale	Shale, blue or brown, dolomitic; with dolomite lenses; phosphatic depauperate fauna in lower few feet	108–240		
Galena	Dubuque		Noncherty unit	Buff or sandy	Dolomite, yellowish-buff, thin- to medium-bedded; with interbedded dolomitic shale	35–45	120	225
	Stewartville				Dolomite, yellowish-buff, thick-bedded, vuggy; *Receptaculites* in lower part	37–47		
	Prosser	P			Dolomite as above; bentonite rarely at midpoint	38		
		A	Cherty unit	Drab	Dolomite, drab to buff, thick- to thin-bedded; cherty; bentonite at base	32	105	
					Dolomite as above; *Receptaculites* at top	6		
					Dolomite as above; cherty	6		
					Dolomite as above; some chert; *Receptaculites* at midpoint	26		
		B			Dolomite as above; little chert; *Receptaculites* abundant	15		
		C			Dolomite as above; much chert	10		
		D			Dolomite as above;	10		
Decorah	Ion			Gray beds	Dolomite and limestone, light-gray, argillaceous; grayish-green dolomitic shale	11–15	20	32–44
				Blue beds	Dolomite, limestone, and shale as above, but darker	5–9		
	Guttenberg			Oil rock	Limestone, brown, fine-grained, thin-bedded, nodular, conchoidal; dark-brown shale	12–16		
	Spechts Ferry			Clay bed	Shale, green, fossiliferous; greenish-buff fine-grained limestone; phosphatic nodules near top; bentonite near base	0–8		
Platteville	Quimbys Mill			Glass rock	Dolomite and limestone, dark-brown, fine-grained, sugary, medium-bedded, conchoidal; dark-brown shale especially at base	0–18		55–75
	McGregor			Trenton	Limestone and dolomite, light-gray, fine-grained	13–18	30	
					Limestone, light-gray, fine-grained, thin-bedded, nodular, conchoidal	12–17		
	Pecatonica			Quarry beds	Dolomite, brown, medium-grained, sugary, thick-bedded; blue-gray where unweathered	20–24		
	Glenwood			Shale	Shale, green, sandy	0–3		
St. Peter				Sand rock	Sandstone, quartz, medium- to coarse-grained, poorly cemented, crossbedded	40+		

FIGURE 3.—Detailed stratigraphic column of Platteville, Decorah, and Galena formations in zinc-lead district.

Platteville formation—Continued	*Thickness (feet)*
McGregor limestone member—Continued	
Limestone, light-gray, very fine grained, very dense, sublithographic; in very thin and wavy beds with thin calcareous shale partings that become thinner below; the shales are light grayish blue, mottled, very fossiliferous; the unit weathers slightly recessed	4.0
Limestone like next above, but beds are not quite so thin; fossiliferous; zone of poorly preserved gastropods 1.7 feet above base, shaly zone at base	3.6
Limestone, dolomitic, light-gray, fine-grained; very slightly argillaceous, very fossiliferous, medium bedded; indistinct argillaceous partings, now wavy; secondary calcite, also limonite, especially in basal 0.6-foot	3.6
Total, lower McGregor	15.1
Pecatonica dolomite member:	
Dolomite, light-grayish-brown, very coarse-grained and vuggy; upper 2 feet are a mixture of rock of this lithologic character and a somewhat argillaceous finely granular laminated dolomite; a 1-foot bed of very vuggy dolomite from 1.8 to 2.8 feet above base, which is shaly in lower part; stylotitic partings 1 foot above base	4.8
Dolomite, medium-gray, laminated, somewhat argillaceous, finely granular; fossiliferous, especially in lower 0.9-foot; medium to heavy bedded; shaly at top; weathers brownish in lower 2.5 feet	6.9
Dolomite, medium-gray, laminated, argillaceous; very fossiliferous partings	3.6
Dolomite, light-grayish-brown; very coarse grained and vuggy; thin gritty dolomitic and platy brownish shale parting at top	1.4
Dolomite, medium-gray, laminated, somewhat argillaceous, fine grained	2.8
Dolomite, medium-gray, laminated, argillaceous; silty and sandy, with fine to coarse quartz grains similar to those of the St. Peter, phosphate nodules abundant (especially in two zones, one at base, the other 1 foot above base)	2.0
Total, Pecatonica	21.5
Glenwood shale member:	
Shale; sandy with rounded quartz grains, khaki to drab in color, soft; phosphate nodules	0.4
Shale; sandy, olive to grayish-brown, mottled yellowish brown, friable	.2
Shale; sandy, medium- to dark-gray, olive, blocky, very hard	.6
Shale; medium-gray, block, hard, sandy; streak of carbonaceous material at top	.3
Total, Glenwood	1.5
Total, Platteville	54.3

St. Peter sandstone:	*Thickness (feet)*
Sandstone, red and white; rounded, frosted, coarse to medium grains	0.1
Sandstone, gray, pinkish, very friable	.2
Sandstone, brown, iron-cemented, hard	0–.1
Sandstone, yellow to gray, very friable; with irregular lower surface	1.3
Sandstone, light-gray, very friable	.1
Sandstone, yellow to dark-brown, laminated, hard	.2
Sandstone, gray and yellow, hard; irregular lower surface	1.1
Sandstone, like next above, but medium to fine grains; spalls	7+

The Platteville formation has been correlated with the Black River group of New York (Kay, 1935, p. 288).

Glenwood shale member.—The Glenwood shale was named by Calvin (1906, p. 75) from exposures in Glenwood township, T. 98 N., R. 7 W., a few miles northwest of Waukon, Iowa (fig. 1, locality 15). In the mining district it is recognized as green arenaceous shale and argillaceous quartz sandstone; in most places it is less than 3 feet thick. The quartz sand is similar to the St. Peter sandstone. Dark-brown to black phosphatic pebbles are found near the top of the unit. In lithologic character this unit grades downward into the St. Peter sandstone, and the overlying contact with the Pecatonica dolomite member is conformable.

Commonly the sand grains of the Glenwood are cemented by pyrite, less commonly by iron oxide. The pyrite is apparently more abundant in areas where zinc, lead, and iron minerals are found in the beds above. Locally, small amounts of zinc and lead minerals have been found in the Glenwood (Heyl, Lyons, Agnew, 1951, p. 20).

Pecatonica dolomite member.—Hershey (1894, p. 175) named the Pecatonica dolomite member from exposures in the Pecatonica River valley, in southwestern Green County just north of the Wisconsin-Illinois State line (pl. 1). In the zinc-lead district the Pecatonica is a brown sugary dolomite that ranges from 20 to 24 feet thick. The rock is medium grained, granular, and thick to thin bedded; the lowermost bed contains large phosphatic pebbles that are similar to the smaller ones in the underlying Glenwood shale member. Grains of clear quartz sand are common in the lower 2 feet of dolomite. Subordinate amounts of brownish-gray platy dolomitic shale occur locally along bedding planes, especially in the upper, more thinly bedded part of the unit. The Pecatonica dolomite member rests conformably upon the Glenwood shale member and grades upward into the McGregor limestone member (fig. 4).

The Pecatonica dolomite member is a poor host for lead and zinc minerals, and only locally does it contain

FIGURE 4.—McGregor limestone member, thin-bedded limestone overlying Pecatonica dolomite member, thick-bedded dolomite. Roadcut, U. S. Highway 151, in Wisconsin, NW¼NE¼, sec. 12, T. 2 N., R 2 W.

even small quantities of galena and sphalerite. Evidence of iron mineralization is similarly uncommon, although large quantities of pyrite and marcasite were noted in samples from holes drilled at the Alderson mine (SE¼ sec. 32, T. 2 N., R. 2 E.) 2 miles northwest of Shullsburg (fig. 1, locality 16), and in USGS drill hole 1*b* at the Crow Branch area near Livingston, Wis. (Heyl, Lyons, Agnew, 1951, p. 17–18).

Building stone has been quarried in most parts of the district from the Pecatonica dolomite member; this fact has caused this member to be called locally the "quarry rock" (Strong, 1877, p. 682).

McGregor limestone member.—The McGregor limestone member was named by Kay (1935, p. 286) from beds exposed in a ravine a mile west of McGregor, Clayton County, Iowa, sec. 28, T. 95 N., R. 3 W. (fig 1, locality 17). The McGregor member consists of thin- to medium-bedded light-gray to buff limestone and dolomite (fig. 4), and ranges in thickness from 23 feet at the type locality to about 30 feet in the central and eastern parts of the zinc-lead district. In general, the McGregor member is divisible into a lower, thin-bedded light-gray crystalline sublithographic limestone with thin grayish shale partings, and an upper, thin- to medium-bedded light-gray to buff granular less fine grained limestone or dolomite. The limestone is argillaceous. Regional dolomitization is illustrated by the lithologic character of the limestone of the McGregor member in the western part of the mining district, the limestone and dolomite in the central part, and the dolomite in the eastern part (Agnew, 1956). The McGregor member, gradational in lithologic character with the Pecatonica member below, is conformably overlain by the Quimbys Mill member (fig. 5).

The McGregor member, which was called Trenton in old geologic reports (Whitney, 1862, p. 33) and by miners even today, contains commercial zinc-lead deposits. Zinc-lead ore has recently (1948–52) been found in large quantities in these beds south of Shullsburg, Wis., and south of Galena, Ill. These beds have been mined for zinc and lead at the Mulcahy mine, sec. 9, T. 1 N., R. 2 E., and the Lucky Hit mine, sec. 33, T. 2 N., R. 2 E. (fig 1, localities 18 and 16), northwest of Shullsburg, Wis. Occurrences of zinc-lead ore have been found at other places such as in a Ewing-Cook mine drill hole, sec. 12, T. 1 N., R. 1 E. (locality 19), and, according to Lincoln (1947), in a Last Chance mine drill hole, sec. 3, T. 5 N., R. 1 W. (locality 20). The ore-bearing potential of the McGregor member appears to be greater in the eastern and central parts of the district than in the western part. Where mineralized, the McGregor member has been leached to a grayish clayey mass and reduced in thickness.

Quimbys Mill member.—Agnew and Heyl (1946, p. 1585) named the Quimbys Mill member from its exposure in the quarry at Quimbys mill, sec. 11, T. 1 N., R. 1 E., 5 miles west of Shullsburg, Wis. (fig. 1, locality 21; fig. 5). At the mill the member consists of about 6 feet of medium-bedded light-brown crystalline sublithographic limestone overlain by an equivalent thickness of thin- to medium-bedded light-brown finely granular dolomite. Thin dark-brown carbonaceous shale partings separate the beds, and a thicker (as much as 3 inches) shale marks the base of the unit. The limestone and dolomite are streaked with brownish organic material. The limestone and dolomite break with a conchoidal fracture; this type of fracturing has led to the name "glass rock" that has been applied to these beds since 1862 (Whitney, 1862, p. 163). The Quimbys Mill member thins to the west, and less than

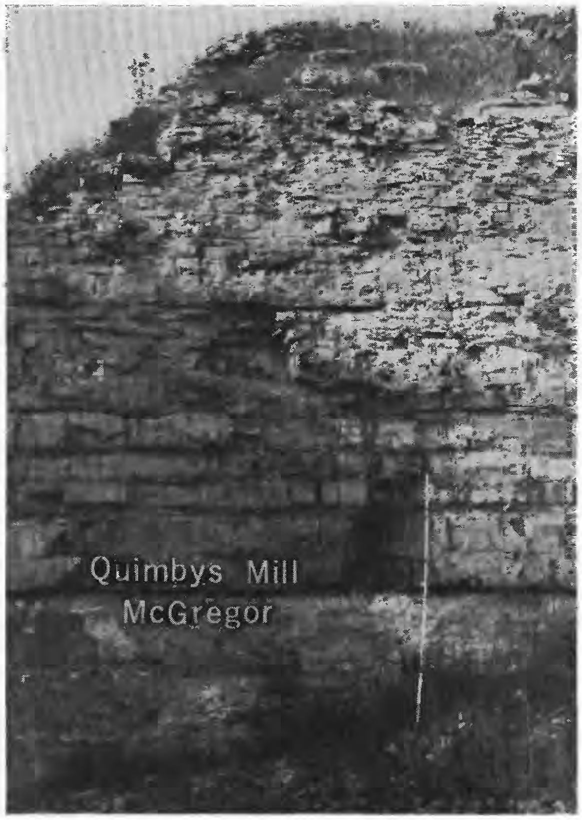


FIGURE 5.—Type section, Quimbys Mill member. Quarry, SE¼ sec. 11, T. 1 N., R. 1 E., Wisconsin.

a foot of "glass rock" is seen at Dubuque, Iowa. South of Shullsburg, Wis., more than 18 feet of "glass rock" is commonly found. Regional dolomitization eastward is shown by the complete dolomite section seen at Gratiot, Wis., and in the eastern part of the district (Agnew, 1950; Herbert, 1946). The Quimbys Mill member conformably overlies the McGregor limestone member of the Platteville formation, but is overlain disconformably by the Decorah formation (Agnew and Heyl, 1946).

The Quimbys Mill member locally called ("glass rock"), one of the ore-bearing zones, has been prospected and mined, particularly since 1940, owing in part to recommendations of the U. S. Geological Survey (Agnew and Heyl, 1947, p. 228). Alteration effects of the solutions that introduced the lead and zinc minerals are shown by silicified, dolomitized, and solution-thinned local areas of Quimbys Mill. The Quimbys Mill member very locally has been thinned to as little as one-third of its normal thickness. Dolomitization has produced a coarser grained saccharoidal rock.

The limestone of the "glass rock" of local usage is suitable for a facing stone and has been used for that purpose in many areas, particularly in the central part of the district.

DECORAH FORMATION

General description.—Calvin (1906, p. 61) applied the name Decorah to the shales that occur between the "two parts of . . . the Trenton limestone," the Platteville below and the limestone of the Galena above, as these beds were exposed in the city of Decorah, Winneshiek County, Iowa, secs. 15 and 16, T. 98 N., R. 8 W. (fig. 1, locality 22). At Decorah, Calvin found 25 to 30 feet of shale with nodules and bands of limestone. Kay (1929, p. 640) defined the Decorah formation as consisting not only of the shale at the type locality, but also "any beds in the region that are of the same age as the shale beds, regardless of lithology." Kay (1928, p. 16) subdivided the Decorah into Spechts Ferry shale and limestone (below), Guttenberg limestone and shale, and Ion limestone and shale (above).

Good exposures of the Decorah formation can be seen in the following localities: (1) Western part of the district, a roadcut along U. S. Highway 52 at north edge of Guttenberg, Clayton County, Iowa, SW¼ sec. 5, T. 92 N., R. 2 W. (fig. 1, locality 23; fig. 6); (2)

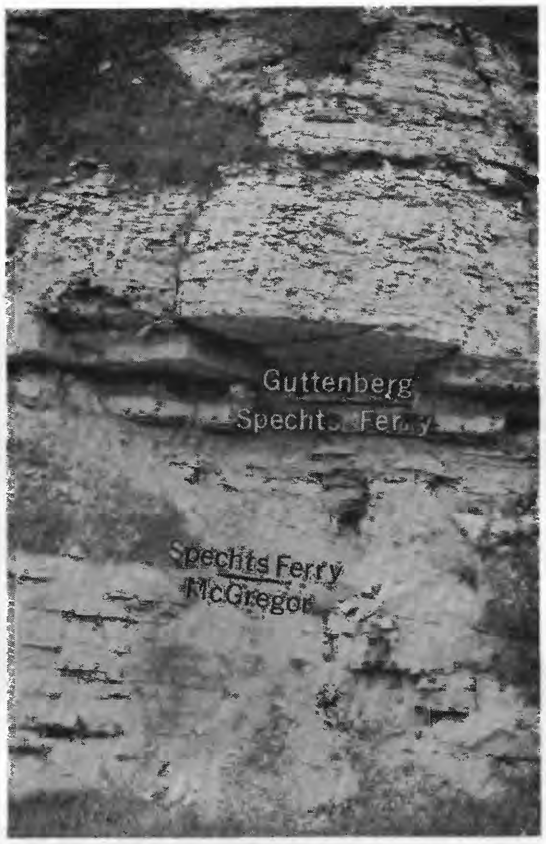


FIGURE 6.—Spechts Ferry member, shale and limestone, overlain by Guttenberg member thin-bedded limestone, and resting on McGregor member, medium-bedded limestone. Roadcut, U. S. Highway 52 in Iowa, SW¼ sec. 5, T. 92 N., R. 2 W.

central part, a ravine into Fever River, just northeast of Benton, Wis., NE¼, sec. 4, T. 1 N., R. 1 E. (fig. 1, locality 24); (3) eastern part, a quarry in south part of Darlington, Wis. (fig. 1, locality 14).

In the western part of the mining district the Decorah formation is limestone and shale, as Kay described it, and the formation approximates 44 feet in thickness. In the central part of the zinc-lead district the Spechts Ferry member is about the same in lithologic character as to the west; the Guttenberg and Ion members, however, have lost much of their shale, and regional dolomitization has affected the upper part of the Ion member (Agnew, 1950). The thickness of the Decorah formation in the central area is approximately 41 feet, owing principally to a decrease in thickness of the Spechts Ferry member. Farther east, at Darlington, the Spechts Ferry is essentially lacking, and the Guttenberg and Ion members are both dolomite, owing to the regional dolomitization; the Decorah in this area is only about 30 feet thick.

An excellent exposure in the central part of the mining district of all but the upper few feet of Decorah is seen in a steep ravine from the west into the Galena River near the center of the east line of sec. 4, T. 1 N., R. 1 E. (fig 1, locality 24), as follows:

	Thickness (feet)
Galena dolomite:	
Prosser cherty member (D beds):	
Dolomite; brownish, medium crystalline, thin-bedded, mottled with calcareous areas	2.2
Limestone; buff-flesh colored, thin-bedded	1.0
Covered (6.8).	
Decorah formation:	
Ion dolomite member (gray beds):	
Limestone, light-buffish-gray, argillaceous, thin-bedded	9.4
Limestone, grayish-buff, coarsely crystalline, very fossiliferous; a 0.1-ft, platy grayish shale at base	2.0
Ion dolomite member (blue beds):	
Limestone, bluish-gray, alternating with grayish-buff; thin-bedded in lower 0.5-ft	1.2
Limestone, greenish-gray, shaly, platy	.7
Limestone, fossiliferous	.7
Limestone, grayish-buff and bluish, crystalline, mottled, argillaceous; upper 0.4 ft. very fossiliferous	1.4
Limestone, thin-bedded; lower part bluish gray, upper part flesh colored	1.0
Limestone, bluish-gray; medium to coarsely crystalline; fossiliferous	1.0
Total, Ion	17.4+
Decorah formation—Continued	
Guttenberg limestone member (oil rock):	
Transition beds: limestone, buffish, medium-crystalline, fossiliferous	0.9
Limestone, brown, thin-bedded, fine-grained, fossiliferous; band of chert nodules 3.5 ft below top	5.0
Limestone, brown, fine-grained, dense, nodular; inter-bedded, brown, platy shale	6.3
Total, Guttenberg	12.2
Spechts Ferry shale member (clay bed):	
Shale, olive, calcareous; trace orange bentonite (?)	0.4
Limestone, light-brown to cream; fossil fragments and phosphate nodules	.8
Shale, olive; brown and green, mottled, fine-grained, argillaceous limestone; brown, platy shale	.1
Limestone, light-brown, fine-grained, dense, nodular	1.1
Limestone, light-brown, dense nodular, wavy-bedded; parting of tan platy shale at top	.1
Limestone and thin platy tan shale	.1
Bentonite	0.1–.2
Limestone, greenish-buff, nodular, argillaceous and light-brown interbedded shale	.3
Total, Spechts Ferry	3.0
Total, Decorah	32.6+
Platteville formation:	
Quimbys Mill member (glass rock):	
Limestone; light-brown to brown, thin- to medium-bedded, very fine-grained and dense, conchoidal fracture; dolomitic shaly zone at base	8.0

The Decorah formation rests disconformably on the Platteville and grades upward into the Galena dolomite (Agnew, 1950), despite Kay (1932) and Atwater's (Kay and Atwater, 1935) "evidence" of an unconformity at the Galena contact. Studies of numerous outcrops in the region from Rockford, Ill., on the southeast to Decorah, Iowa, on the northwest, amply supplemented with the examination of cuttings from wells have shown the Decorah-Galena contact to be a conformable one regionally; and detailed studies of closely spaced outcrops in many areas of the mining district indicate that these relations remain constant.

It is the considered opinion of the writers that the sections of Kay and Atwater were incorrectly described and that the "clastic beds" which are said to mark this disconformity are actually altered strata in mineralized outcrops or weathered exposures heavily covered with loess and other surficial material (Agnew, Heyl, Behre, Lyons, 1956, p. 294–295).

The Decorah formation is probably all of Trenton age, although Kay (1929, p. 666) thought that the Spechts Ferry (together with the lower Guttenberg strata) could be correlated with his Glenburnie member of the Chaumont (upper Black River) of New York because of the bryozoa. Furthermore, he (1934, p. 330) believed that the bentonite near the base of the Spechts Ferry is "identical with the Hounsfield bentonite in the Glenburnie."

Spechts Ferry shale member.—Kay (1928) named the lower, shaly part of the Decorah formation from its exposure at Spechts Ferry Station, Dubuque County, Iowa (fig. 1, locality 12). In the western part of the mining district the Spechts Ferry shale member consists of green fossiliferous shale and some greenish-buff limestone lenses, 7 to 8 feet in thickness (locality 13). Near the base is a thin grayish plastic seam of bentonite, and in the upper part of the unit limestone nodules carry small dark-brown phosphatic pellets. The Spechts Ferry member thins to the east (locality 24) and is only a foot thick at Shullsburg, Wis., where it is limestone and shale; also at Shullsburg, the bentonite at the base and the phosphatic pellets at the top are characteristic. In exposures west of Platteville *Pionodema* is characteristic. The Spechts Ferry member rests disconformably on the uppermost beds of the Platteville formation and grades upward into the Guttenberg member (fig. 6).

Disseminated sphalerite and galena are common in the Spechts Ferry shale member, especially in places where ore minerals occur in the beds above. However, because the unit is thin and because it is difficult to mine and mill for the zinc and lead content, the Spechts Ferry is not considered an ore zone by some miners. Disseminated pyrite crystals are even more widespread than zinc and lead minerals.

During the middle 1800's the bentonite in the Spechts Ferry member was used in a few places as a pipe clay and has long been locally known as the "claybed."

Guttenberg limestone member.—The Guttenberg member was named by Kay (1928) from its exposure at the north edge of Guttenberg, Clayton County, Iowa (fig. 1, locality 23; fig. 6). At the type locality and elsewhere in the western part of the mining district the Guttenberg limestone member is a pinkish thin-bedded sublithographic argillaceous fossiliferous limestone with intercalated thin wafers of reddish brown shale, in all totaling 16 feet in thickness. In the central part of the zinc-lead district the limestone is light brown and the shale chocolate brown and carbonaceous, and its total thickness averages 14 feet (fig. 1, locality 24). In the eastern part of the mining district the rock is mainly light-brown argillaceous dolomite and brown shale, aggregating 10 to 12 feet; the dolomite originated from regional dolomitization (Agnew, 1950, Herbert, 1946). Farther east the Guttenberg thins to less than 7 feet of dolomite, as at Blanchardville, Green County, sec. 22, T. 4 N., R. 5 E. (fig. 1, locality 25). West of Platteville *Hesperorthis* and *Sowerbyella* are characteristic. The Guttenberg member grades below into the Spechts Ferry shale member (fig. 6), and upward into the Ion dolomite member.

Beds of the Guttenberg limestone member were variously altered by the mineralizing solutions that formed the zinc-lead deposits. Dolomitization produced a saccharoidal texture. Silicification locally produced chert nodules; these nodules are not to be confused with the band of chert nodules approximately 2 feet below the top of the Guttenberg, which antedated the lead-zinc mineralization. Solution of calcareous beds resulted in a concentration of brown shale and the brownish argillaceous material of the limestone, resulting in the oil rock of the miners (fig. 38). All gradations are seen. In the northern part of the district, the Guttenberg is known to some miners as the brown rock (Strong, 1877, p. 695).

The Guttenberg member (or oil rock) contains zinc and lead ore in many places. In the deposits in this member the sphalerite and galena are disseminated, as in the underlying Spechts Ferry member. Veins are also present in many places and are mineable particularly where the overlying strata are mineralized.

Ion dolomite member.—The Ion member was named by Kay (1928) for exposures near Ion, Allamakee County, Iowa, sec. 35, T. 96 N., R. 4 W. (fig. 1, locality 26). In the western part of the zinc-lead district the Ion is made up of grayish medium-crystalline limestone and some grayish-green calcareous fossiliferous shale. Eastward across the mining district the rock becomes dolomite owing to regional dolomitization, and the amount of shale diminishes so much that near Shullsburg, Wis., only argillaceous streaks in the dolomite remain. West of Platteville *Prasopora* marks its upper boundary, and *Glyptorthis* is characteristic in the lower part. In contrast to the Spechts Ferry and Guttenberg members below, the Ion maintains its thickness of about 20 feet across the district. The Ion dolomite member grades downward into the Guttenberg limestone member and upward into the Galena dolomite.

The Ion member was dissolved and thinned by the zinc- and lead-bearing solutions, but reduction in thickness rarely exceeded more than a foot or two. Similarly, the beds were locally dolomitized by mineralizing solutions, which resulted in a general bleaching from light gray to a cream color and a decrease in porosity. This dolomitization contrasts with the regional dolomitization, which resulted in vuggyness and an increase in porosity.

In much of the mining district, the lower beds of the Ion member are called blue and the upper beds gray because of their colors; in the northern part of the district the Ion is referred to by some as green rock (Strong, 1877, p. 695).

The Ion member is ore bearing and, together with the overlying beds of the Galena dolomite, constitutes one of the host rocks of most pitch and flat deposits.

GALENA DOLOMITE

These beds, part of the upper magnesian limestone or cliff limestone (Owen, 1840, p. 19, 24), were designated as Galena limestone by Hall (1851, p. 146) from their exposure in the vicinity of Galena, Jo Daviess County, Ill. (pl. 1).

In the central and eastern parts of the mining district the Galena is dolomite, whereas in the western part it grades into limestone, especially in the lower, or cherty, part. The dolomite, which originated from regional dolomitization, is a vuggy porous rock. The limestone to the west is crystalline and more dense.

In the upper Mississippi Valley region the Galena dolomite has been divided into the following three members principally on the basis of paleontologic criteria:

Dubuque shaly member (Sardeson, 1907, p. 193)—limestone and shale, bounded below by the "cap rock" of the Stewartville member; named from Dubuque, Iowa (pl. 1).

Stewartville massive member (Ulrich, 1911, pl. 27)—the *Maclurea* zone (Winchell and Ulrich, 1894, p. lxxxiii–lxxxvii) of Minnesota; named from Stewartville, Fillmore County, Minn., 65 miles northwest of Waukon, Iowa.

Prosser cherty member (Ulrich, 1911, pl. 27 and p. 488—*Fusispira* (above), *Nematopora* and *Clitambonites* (below) (Winchell and Ulrich, 1894, p. lxxxiii–lxxxvii) beds of Minnesota; named from Prosser's ravine, near Wykoff, Minn., 50 miles northwest of Waukon, Iowa.

In much of the zinc-lead district the Galena is dolomite, and is only sparsely fossiliferous; the fossils that are present in exposures are poorly preserved. Furthermore, where seen in the mines and in cuttings from prospect churn-drill holes, local rock alteration and pulverization by drilling have destroyed most of the fossils that survived the effects of regional dolomitization. As a result, it was necessary to subdivide the Galena on the basis of lithologic criteria. The units that can be recognized in exposures are as follows:

	Thickness (feet)
Noncherty unit:	
Dubuque shaly member—dolomite and dolomitic limestone; yellowish gray, finely granular, argillaceous, thin to medium bedded; thin partings of dolomitic, yellowish-gray shale; lower contact gradational	35–45
Noncherty unit—Continued	
Stewartville massive member and upper part of Prosser cherty member (fig. 3, *P* beds)—dolomite; yellowish buff, coarsely granular to crystalline, vuggy, medium to thick bedded; *Receptaculites* common 35–55 feet above base	75–85
Cherty unit:	
A beds—dolomite; buff to drab, otherwise as above; chert bands common in upper 44 and 50 to 56 feet below top; locally a thin bentonite about 32 feet below top; *Receptaculites* at 35–40 feet below top and at 10 feet above base	70
B beds—dolomite as above, except more brownish in color; chert bands rare; *Receptaculites* common, locally called "lower Receptaculites zone"	15
C beds—dolomite as above; chert bands common, locally called "lower chert"	10
D beds—dolomite as above, except for streaks of greenish argillaceous material; no chert, locally called "lower buff"	10
Total Galena	225

Honeycomb weathering is characteristic of all parts of the Galena dolomite except the Dubuque member of the noncherty unit (fig. 7).

The thickness of the Galena dolomite is 220–230 feet in the mining district.

The Galena dolomite is the uppermost bedrock in most of the district, except in areas of deep stream dis-

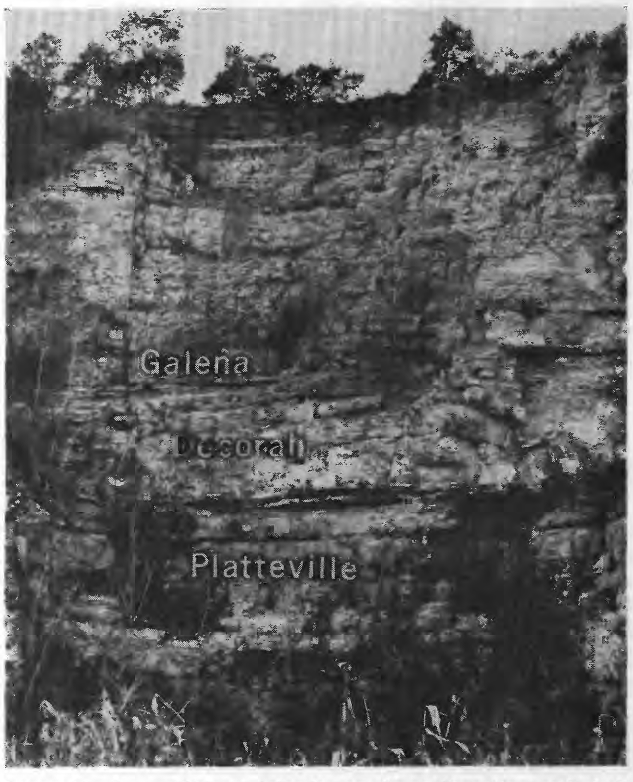


FIGURE 7.—Vuggy Galena dolomite overlying limestone and shale of the Decorah formation, and limestone of the Platteville formation. Bluff, SW¼ sec. 35, T. 4 N., R. 5 W., Wisconsin.

section or structural uplift. Good exposures of the Galena are as follows:

Quarry, Loras College, Dubuque, Iowa, SE¼ sec. 23, T. 89 N., R. 2 E.—noncherty unit (fig. 1, locality 27).

Quarry, Eagle Point, at northeast edge of Dubuque, Iowa, SE¼ sec. 7, T. 89 N., R. 3 E.—lower part of noncherty unit, all of cherty unit (fig. 1, locality 28).

Roadcut, State Highway 11, west of Hazel Green, Wis., N½ sec. 34, T. 1 N., R. 2 W.—lower part of noncherty unit, and cherty unit *A* beds (fig. 1, locality 29).

Quarry one-half mile east of Barneveld, Iowa County, Wis., NE¼ sec. 10, T. 6 N., R. 5 E.—cherty unit *B*, *C*, and *D* beds (fig. 1, locality 30).

Quarry, south edge Darlington, Wis. (fig. 1, locality 14)—cherty unit *B*, *C*, and *D* beds.

The Galena dolomite grades downward into the Decorah formation and is overlain with apparent conformity by the Maquoketa shale.

The Galena dolomite, called by the miners the yellow sandy (noncherty unit) and the drab (cherty unit), [7] is an important rock for lead and zinc ores. Pitch and flat zinc-lead deposits occur in the lower part (*B*, *C*, and *D* beds of the cherty unit) and lead, zinc, and, locally, copper deposits along joints are found throughout the formation. Most of the lead ore produced in the district was mined from this formation.

Evidence of alteration of the Galena dolomite during mineralization are not pronounced. The more calcareous parts of the dolomite have been partly dissolved by the ore solutions to form a porous honeycomblike rock in most of the ore deposits in this formation. Dolomite produced during mineralization was seen in only a very few localities as a bleached cream-colored rock, less porous than is normal. Silica overgrowths, on bedded chert nodules, and silicified fossils are the main evidences of silicification.

The Galena dolomite is the principal source of water for most of the farms in the mining district and is quarried in places for road metal. The Dubuque shaly member is used for building stone.

UPPER ORDOVICIAN SERIES

MAQUOKETA SHALE

The name Maquoketa shales was applied by White (1870, p. 181) to the shales exposed along the Little Maquoketa river about 12 miles west of Dubuque, Iowa (pl. 1). In the mining district Maquoketa shale occurs below and at the bases of the erosional remnants called mounds. These mounds in Wisconsin are 4 and 7 miles east of Platteville, 16 miles south of Platteville at Sinsinawa, and 25 miles northeast of Mineral Point at Blue Mounds. Elsewhere in Wisconsin the Maquoketa shale crops out in the uplands south of Shullsburg and along the Grant-LaFayette County line south of Platteville (Grant and Burchard, 1907); in Illinois and Iowa it is exposed next to the escarpment of southward-dipping beds of Early Silurian age (pl. 1) (Grant and Burchard, 1907; Shaw and Trowbridge, 1916), which extends eastward and northwestward from Galena, Ill.

The Maquoketa shale is principally blue or gray dolomitic silty shale with some grayish-buff medium-granular argillaceous thin-bedded dolomite; however, the lower 30 to 40 feet of the formation is commonly brown in color. In the basal few feet—the "depauperate zone" (Ladd, 1929, p. 371–375)—phosphatic pebbles and fossils are present. Away from the mining district the Maquoketa varies greatly in lithologic character; to the west, south, and east dolomite is more abundant than shale. Furthermore, the thickness is not constant within the district. A few miles south of Galena, Ill., in U. S. Bureau of Mines Mougin diamond-drill hole (Zinner and Lincoln, 1946), SE¼ sec. 10, T. 27 N., R. 1 E. (fig. 1, locality 31), the Maquoketa is only 108 feet thick; [8] 8 miles south of Shullsburg, Wis., T. T. Redfern well, SE¼ sec. 34, T. 29 N., R. 2 E. (fig. 1, locality 32) it is at least 170 feet thick;[8] at West Blue Mound, Wis. in WIBA–FM transmitter station well, NW¼ sec. 1, T. 6 N., R. 5 E. (fig. 1, locality 33) it is 240 feet thick; [9] and in Fayette County, Iowa, it is about 260 feet thick (Savage, 1905, p. 486). At the top of the Maquoketa shale where it is thickest a reddish hematitic clay and pebble unit has been reported (Workman, 1950) outside the mining district in Illinois. This unit, called the Neda formation by Savage and Ross (1916), probably represents an unconformity between the Maquoketa and the overlying dolomite of Early Silurian age. A good exposure of the upper part of the Maquoketa shale can be seen along U. S. Highway 52 at the south edge of Bellevue, Iowa, NE¼ sec. 19, T. 86 N., R. 5 E. (fig. 1 locality 34; fig. 8); the lowermost beds, including the "depauperate zone," can be seen in the railroad cut just west of Scales Mound, Ill., SW¼ sec. 26, T. 29 N., R. 2 E. (fig. 1, locality 35).

The Maquoketa shale is a poor host rock for zinc and lead minerals. In the Glanville prospect at Scales Mound, Ill., NW¼ sec. 24, T. 29 N., R. 2 E. (fig. 1, locality 36) a short adit was driven for sphalerite and barite in dolomite in the middle of the formation; the minerals do not occur in paying quantity. In some of the more dolomitic beds pyrite is common, and when associated with the phosphatic "depauperate zone" in many places it is abundant.

The basal part of the Maquoketa shale contains much organic material and in many places gives an oily scum

[7] In the northern part of the district (15 miles northwest of Mineral Point) some miners call these beds "wool rock."

[8] Detailed data supplied by Illinois Geological Survey, Urbana, Ill.

[9] Data supplied by Wisconsin Geological and Natural History Survey, Madison, Wis.

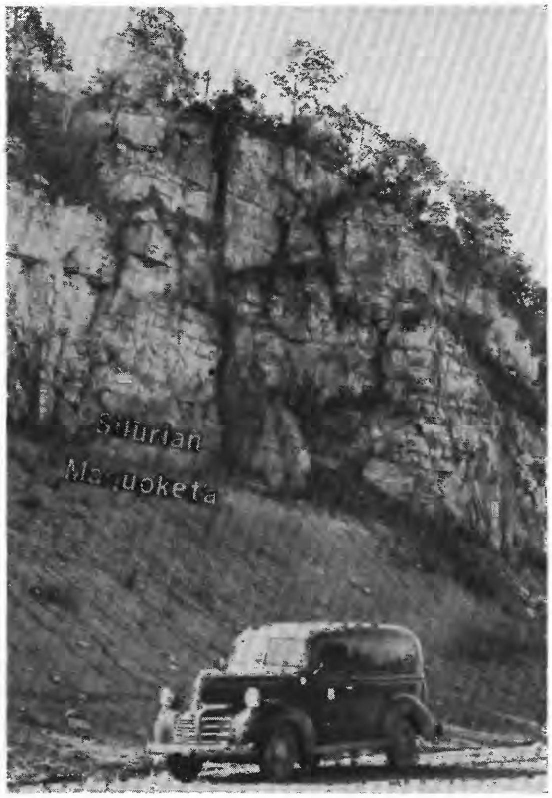


FIGURE 8.—Upper part of Maquoketa shale overlain by dolomite of Early Silurian age; Quarry and roadcut, U. S. Highway 52, NE¼ sec. 19, T. 86 N., R. 5 E., Iowa.

to the water bailed during the drilling of wells and prospect holes. At the Staderman gold mine, Eleroy, Ill., the basal shale was mined for several years as a paint filler.

SILURIAN SYSTEM

The rocks of Silurian age were named Niagara dolomite by James Hall (1862), and are still locally referred to by this name. They are found only in the mounds and at the southern and southwestern edges of the mining district, where erosion of the southward dipping beds has created an escarpment (pl. 1). Excellent exposures of the upper beds are seen in quarries at Platte Mound, NW¼ sec. 5, A. 3 N., R. 1 E (fig. 1, locality 37) and Belmont Mound, northwest corner, sec. 3, T. 3 N., R. 1 E. (locality 38); the lower beds are well exposed at Bellevue, Iowa (locality 34).

The Silurian rocks in the zinc-lead district are mainly yellowish-bluff dolomite, medium to coarsely granular, in part vuggy. They consist of the Edgewood, Kankakee(?) and Hopkinton(?) formations, all of Early Silurian age. Near Galena, Ill., the thickness totals as much as 200 feet (Willman and Reynolds, 1947, p. 7). Near Galena the uppermost 90 feet of dolomite contains chert and is marked at the top by *Pentamerus;* next below occurs approximately 25 feet of noncherty dolomite, both of which units may be Hopkinton limestone; below lies about 65 feet of cherty dolomite, which probably is Kankakee limestone; the basal 20 feet of strata is argillaceous dolomite which is Edgewood limestone. In general, the Silurian rocks differ from the Galena dolomite in being less vuggy and more yellowish; furthermore, the Galena dolomite possesses no beds comparable to the laminated, silty and argillaceous dolomite of the lower part of the Silurian.

Silurian rocks overlie the Maquoketa shale unconformably; the basal argillaceous dolomite of the silty Edgewood limestone formation appears to thicken and thin inversely with the underlying Maquoketa.

An interesting effect of rock alteration is seen at West Blue Mound (fig. 1, locality 33), where the complete sequence of dolomite of Silurian age has been silicified (Whitney, 1862, p. 190).[10] This silicified rock was thought by Hubbard (1900) to have originated from the leaching and weathering of a limestone that contained siliceous fossil shells.

The dolomite of Silurian age, because of its similarity to the Galena dolomite, should be a favorable host rock for zinc and lead deposits. However, as it is present only along the southern and southwestern margins of the mining district, its ore-bearing potentiality has not been tested widely by prospecting. Isolated crystals of sphalerite and galena have been found in many places, and small amounts of galena have been mined at Sherrill Mound, 10 miles northwest of Dubuque, and near Clinton and Anamosa (Calvin, 1895, p. 110), Iowa, which are 30 to 40 miles southeast and southwest of Dubuque, respectively (fig. 1).

South and west of the mining district dolomite of Silurian age contains an adequate source of water for farm wells and is locally quarried for road metal.

DEPOSITS OF POST-SILURIAN AND POSSIBLY PRE-PLEISTOCENE AGE

Several types of deposit of post-Silurian age have been found locally in the mining district. These include—

1. Boulders of quartz sandstone—in anomalous stratigraphic positions, mostly in the Galena dolomite and the Decorah formation. Many of these sandstone boulders are derived from sandstone "dikes" injected into joints or faults from below. A few dikes were deposited as sedimentary filling from above. The origin of a few others is unknown. They occur at many localities in the mining district.
2. Boulders of hematite—near heads of ravines southeast of Hazel Green, Wis. (southwest corner of Lafayette County).

[10] Also in data from the WIBA-FM transmitter well, supplied by Wisconsin Geological and Natural History Survey, Madison, Wis.

3. Boulders of quartzite and greenstone—near head of ravine one-half mile northwest of McCartney, Wis., and 7 miles northwest of Spechts Ferry, Iowa (fig. 1, locality 12).
4. Conglomerate near McCartney, Wis.—poorly cemented and sorted cross-bedded aggregate of local and exotic pebbles and sand at crest of ridges, a mile north and northeast of the village.

These four types of deposits may have been laid down at one or more times since the end of the Silurian period. During Pennsylvanian time sandstone may have been deposited in what is now the mining district; its nearest known northernmost exposure in this general area is only 35 miles south of Dubuque. During Cretaceous time iron-cemented gravels or conglomerates were emplaced in this general area; the closest such deposit is at Waukon, Iowa. It is possible that some of these deposits were laid down during Pleistocene time.

PLEISTOCENE EPOCH

By A. E. Flint

Pleistocene sediments of several types are abundant in the district especially in its eastern and western parts.

DEPOSITS OF GLACIAL ORIGIN

GLACIOFLUVIAL SEDIMENTS

Within the district the valley trains and associated low- and high-level terraces of the Mississippi and Wisconsin Rivers are mostly features of glacial origin. Fill of glaciofluvial material in the Mississippi River valley attains a thickness of more than 300 feet near Dubuque, Iowa, and more than 150 feet near McGregor, Iowa. This channel fill produced the conspicuous flats in the Mississippi and Wisconsin River valleys and, indirectly, in their larger tributaries.

DRIFT

Older glacial deposits are present in the fringes of the district. Except for deposits of Wisconsin age in the vicinity of Prairie du Sac, the drift which marks the eastern boundary of the "Driftless Area" (fig. 9) is of probable Illinoian age. This drift exhibits a well-developed soil horizon. Commonly the upper 3 feet is leached of its calcareous constituents, and locally it is reddish in color. Weathered limestone pebbles are present near the base of the leached zone, and below this zone is unweathered drift which contains much subangular quartz, chert, granite, diabase, quartzite, sandstone, and other erratics. Trowbridge (Trowbridge and Shaw, 1916, p. 90) reported the drift to be more than 90 feet thick 2 miles north of Stockton, Ill., and noted that Leverett had reported 140 to 150 feet of drift northeast of that city. Trowbridge stated that this drift is most probably Illinoian in age.

Local deposits of drift that are probably older than Illinoian are present in the southern fringes of the district. One such deposit is in a small ravine in the NW¼ sec. 26, T. 26 N., R. 2 E., northwest of Hanover, Ill. Across the Mississippi River, in the vicinity of Bellevue, Iowa, are erratic boulders and small patches of drift of pre-Illinoian age. Farther north in Dubuque County, Iowa, extensive areas of Kansas drift are recognized. Still farther north in the vicinity of Guttenberg, Iowa, Nebraskan gravels are found in caves, which were opened by highway construction work, and were apparently introduced through sinks into shallow solution cavities. A similar occurrence of drift may be seen in a quarry half a mile south of Waukon, Iowa, where Nebraskan drift appears to be interbedded with Galena dolomite.

An intensive search throughout the district would probably disclose Pleistocene deposits other than those described above. Isolated erratics have been reported on the hilltops west and south of Galena, Ill. (Willman, H. B., oral communication to Agnew and Heyl, 1945.) Possibly some of the post-Silurian deposits described in the stratigraphic section of this report (p. 19) may have a glacial origin, but the evidence is not conclusive.

LOESS DEPOSITS

The typical loess in the zinc-lead district is light-brown to yellowish-buff and consists mostly of silt. Glacial "rock flour" from valley trains and outwash plains was picked up and transported by the wind and deposited over the upland areas along the bluffs of the river. Prevailing westerly winds appear to account for the larger and more extensive loess deposits east of the Mississippi River and for the progressively finer texture to the east. Many particles of sand size occur in the loess, and deposits of sand occur locally in the bluffs. Commonly the loess contains substantial amounts of carbonate and effervesces freely in dilute hydrochloric acid, except where leached in the upper part of the soil horizon. Numerous gastropod shells, similar to terrestrial forms living today, are present in these deposits. Although unconsolidated, the loess stands in vertical faces in road cuts and other excavations. This lack of erosion by surface runoff is explained by the high permeability of the loess, which permits meteoric waters to percolate readily through it.

Loess is more than 50 feet thick in some places in the Mississippi River bluffs. Although generally thin except for a few miles east of the Mississippi River, the loess extends eastward from the river for a distance of 40 miles or more, where the deposits are less than a foot thick. Much of the upland in Grant County, Wis., is thinly loess covered, and loess is common on the divides in western Lafayette and Iowa Counties, Wis. Most of the divides in the western part of Jo Daviess County, Ill., and in the uplands in the eastern part of Jackson, Dubuque, and Clayton Counties, Iowa, also are covered by loess.

RECENT SEDIMENTS

By A. F. Agnew

Since the Pleistocene epoch, geologic history has recorded almost continuous erosion. This process in late historic times has been accelerated by man's removal of woodlands and natural grasses with the result that gullying, particularly in headwater areas, is common. The increased rate of soil removed from upland areas and valley walls has caused deposition in valley bottoms from overloaded streams. Several lines of evidence show that these deposits have been emplaced in late historic time. A post-Pleistocene black soil zone 2 feet thick overlain by loamy clay to a thickness of 6 feet is present in most of the larger stream valleys. Also, at the beginning of the 20th century, river traffic on the Galena (formerly Fever) River north from the Mississippi River to Galena, Ill., was common. By 1920 the river had so silted its channel that the Fever was no longer navigable. In this connection, also, early reports of the district mention the abundant clear streams. Today, the streams generally are muddy the year around.

PHYSIOGRAPHY

By A. E. Flint

The upper Mississippi Valley zinc-lead district lies essentially within the Driftless Area (fig. 9) where conditions for physiographic investigations are excellent because no mantle of drift is present as in adjacent glaciated areas, and because the topography probably has been altered very little since pre-Pleistocene time. The Driftless Area has been studied by many geologists (such as Chamberlin, 1883, p. 269–270), though not extensively since 1930, and no special physiographic restudy has been made for inclusion in this report even though new data indicate that more work is desirable. The abundant published material presents much information concerning the physiography of the area, and in the preparation of this report frequent reference has been made to Martin (1916, p. 73–170), Grant and Burchard (1907, 14 p.), Shaw and Trowbridge (1916, 13 p.), Trowbridge and Shaw (1916, p. 15–158), Tri-State Geological Field Conference (1948, 28 p.), Kansas Geological Society, 1935, 471 p.), from which both general information and specific data have been freely used.

TOPOGRAPHY

The topography of the Driftless Area differs markedly from the disorder presented by the hilly moraine, swamp, and till-plain topography of the Wisconsin drift areas to the north and northeast and from the gently undulating to nearly flat surfaces of the older areas to the south and southeast of the district.

UPLAND

A remarkably flat upland surface slopes gently southward across the district, and the even horizon is broken only by isolated irregularly conical hills that rise abruptly above this plain. At Mineral Point and Fennimore, Wis., the upland has an altitude of 1,200 feet above sea level; at Lancaster the surface rises only to 1,100 feet; at Platteville, Wis., to 1,040 feet; and at Hazel Green, Wis., to 980 feet above sea level. This upland plain has been called the Lancaster peneplain (Grant and Burchard, 1907, p. 2), but the literature concerned with the Driftless Area indicates that the problem of peneplanation and erosion cycles in this area has not been solved. Because Martin (1916, p. 53) found no evidence to indicate peneplanation since the Paleozoic strata were deposited, he believed that the surfaces in the Driftless area were structural. Trowbridge (1921, p. 7–125) contended that there are two erosion cycles indicated by the Lancaster plain and a higher surface called the Dodgeville peneplain. Bates (1936, p. 65) found evidence for only one peneplain, the Dodgeville surface. Horberg (1946, p. 185–186) found by subsurface studies in Illinois that the buried surface which corresponds to the broad eroded upland plain in the mining district bevelled the structure in one place and followed it rather closely in another. Also, in a personal communication to Horberg (1946, p. 185–186) Trowbridge rejected his earlier conclusions that the Dodgeville is a true peneplain.

For the purpose of this report no special investigation has been directed toward a solution of the erosion-cycle problem.

VALLEYS

The upland surface is maturely dissected for the most part. Shallow open valleys characterize the headwater areas of streams which rise in the district and flow toward the southeast, south, and southwest. Relief is at a minimum in these headwater areas. In contrast, maximum relief is found where the valleys are canyonlike near the junctures of these streams with the Mississippi River. The relief of the district ranges between these two extremes.

An important drainage divide, known as Military Ridge, extends westward from Madison to Prairie du Chien and crosses the northern part of the district in Wisconsin. The summit of this divide marks the crest of the north-facing Galena escarpment; it also marks an abrupt change in topography. All the tributaries to

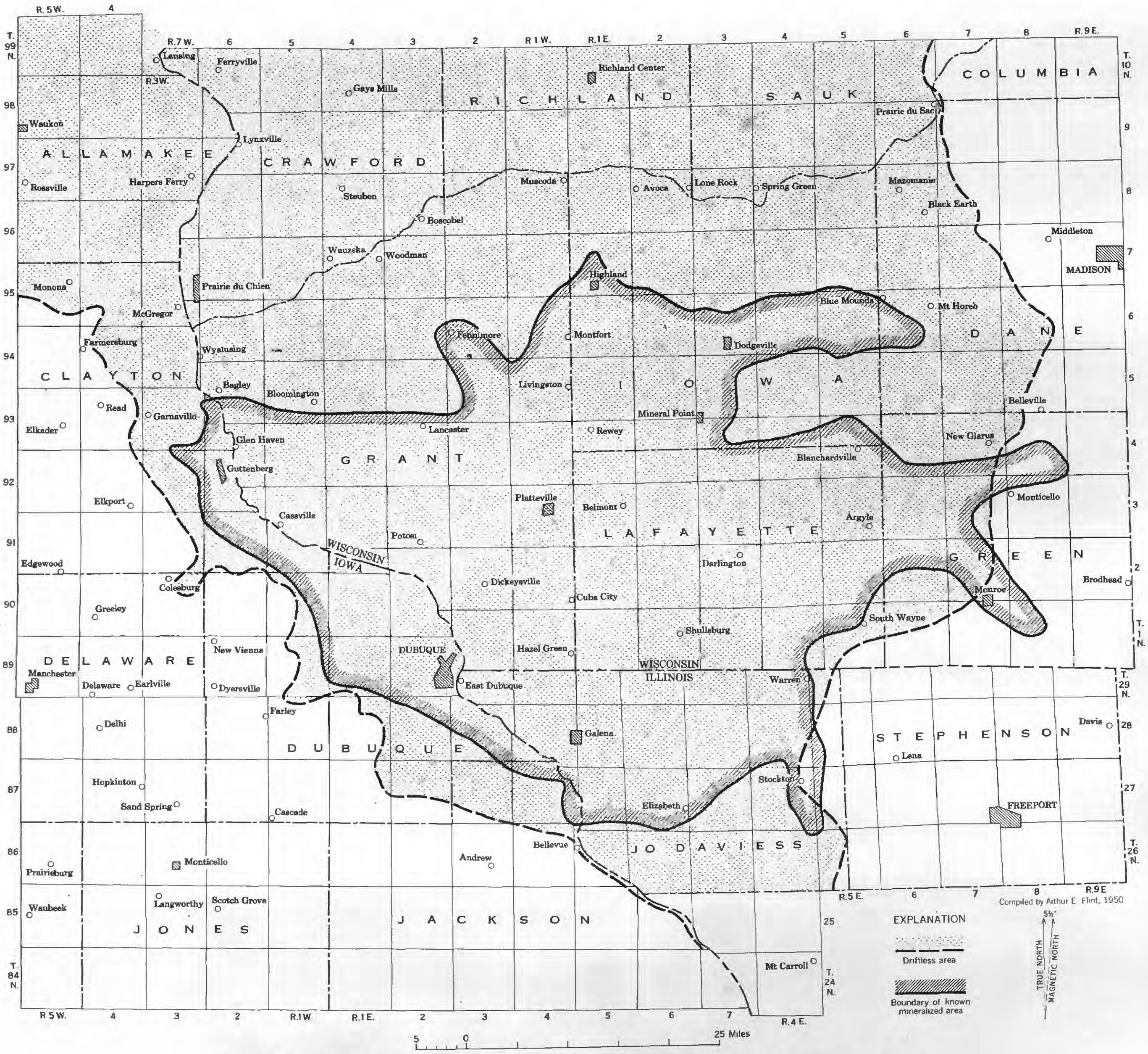


FIGURE 9.—Map of the Driftless Area of the upper Mississippi Valley zinc-lead district.

the Wisconsin River, which lies from 12 to 15 miles to the north of the divide, flow in deeply incised youthful valleys. The gradients of these streams near their headwaters commonly are more than 80 feet per mile, and a generally youthful topography is present. In contrast, a mature topography of rounded divides, open valleys, gentle slopes, and relatively little relief characterizes the central area of the district south of the escarpment.

MOUNDS

The highest altitudes in the district are at the summits of a few monadnocks which are called "mounds." The important ones in Wisconsin (pl. 1) include the two Blue Mounds, 15 miles west of Madison; the three Platte Mounds, 4 to 7 miles east of Platteville; and Sinsinawa Mound, 5 miles west of Hazel Green; others are Sherrill Mound, 11 miles northwest of Dubuque, Iowa, and Scales Mound, 11 miles, and Charles Mound, 13 miles northeast of Galena, Ill. Of these, the West Blue Mound, which rises to approximately 1,720 feet above sea level and about 1,100 feet above the Mississippi River, is the highest.

The mounds are capped by resistant dolomite of Silurian age that commonly develops steeply sloping walls. Below the Silurian the lower slopes of the mounds pass gently across the more easily eroded Maquoketa shale to the surrounding plain. The mounds are probably remnants of an earlier structural plain developed on the dolomite of Silurian age.

MISSISSIPPI RIVER GORGE

The partly filled shallow gorge (Martin, 1916, p. 133) of the Mississippi River forms one of the district's most prominent topographic features (fig. 10). The walls separate the upland surface from the nearly flat river valley bottom and are everywhere steep. The trough is from 1 to 2 miles wide, but normally only a small part of its total width is occupied by the river except in the artificial lake areas above flood control dams. There are three of these dams in the district: at Guttenberg, a mile north of Dubuque, and at Bellevue, Iowa. In other than these ponded areas, the river flows in a sinuous course through a series of braided channels. The cliffed walls of the gorge, which rise from 300 to 600 feet above the flood plain, have been cut, for the most part, through the bluff-forming Galena dolomite. Much of their steepness has been attributed to lateral corrasion by debris-loaded glacial meltwaters that flooded the gorge during the Pleistocene epoch. At the same time, glaciofluvial material, which was deposited in the gorge to depths of 300 feet or more by the overloaded stream, produced the flat bottom, which extends virtually from wall to wall. Little more than a thin veneer of alluvium has been deposited in the channels and on the flood plain since Pleistocene time. The result is a contradictory picture of youthful steep valley walls between which flows a river that has a well developed flood plain and a low gradient, characteristics normally indicative of maturity.

DRAINAGE

The zinc-lead district is drained by the well-integrated Mississippi River system. Marshlands are rare and appear only on the flood plains of the master stream and near the mouths of its tributaries.

Streams throughout the district have a generally dendritic pattern. Rivers in Illinois and in Wisconsin, except for those north of Military Ridge, flow for the most part southward and, in the western part of the district, locally parallel the course of the Mississippi River. North of Military Ridge numerous short youthful streams flow northward into the Wisconsin River.

The dendritic stream pattern is modified somewhat by two features: (1) the entrenched meanders in the lower parts of most of the larger streams tributary to the Mississippi River; and (2) local structural control of stream channels. The entrenched meanders appear to be a second-cycle erosion feature, and, as such, they may have a bearing on the origin of the upland plain. The joint system in the region is locally a factor in determining stream courses. The marked rectangular pattern of the Galena (formerly Fever) River in sec. 3, T. 1 N., R. 1 E., and secs. 34 and 27, T. 2 N., R. 1 E., in Wisconsin (see Agnew, Flint, and Crumpton, 1954) serves as a good example. The open joints in this area extend N. 40° to 55° W., and N. 28° to 35° E. This river flows parallel to one or another of these joint directions for approximately 4½ miles, and for short distances, continuous vertical joint surfaces mark one bank or the other of the river. Also, intermittent streams in headwater areas may be joint controlled. A good example is in sec. 16, T. 29 N., R. 1 W., in Illinois, where ravines in valley heads extend east or west remarkably parallel to the open joints in the area. This type of structural control is caused by settling and slumping of overburden into solution-widened areas of the shallow open joints. Surface runoff is initially directed into those depressions which, if drained externally as most of them are, become rather quickly gullied by erosion.

A second type of structural control is exercised by folds in the strata. In secs. 20, 21, 22, 23 and 24, T. 2 N., R. 1 E., in Wisconsin, (pl. 3), the Galena River turns sharply and flows along the synclinal axis north of the Meekers Grove anticline. The Crow Branch of the Platte River through secs. 15, 16, 22 and 23, T. 5 N., R. 1 W., in Wisconsin, follows the trough of a westward-trending syncline (pl. 8). The Shullsburg Branch of the Galena River, through secs. 4, 7, 8, 9 and 10, T. 2 N., R. 2 E., and in secs. 11 and 12, T. 1 N., R. 1 E., also flows in a syncline (pl. 5).

Several examples of stream rearrangement, of which two are notable, are found in the district. Couler Valley, which extends northwestward from the city of Dubuque, Iowa, for a distance of 5 miles, is a steep-walled straight trench less than half a mile wide (fig. 10). It is the abandoned channel of the Little Maquoketa River and resulted from the beheading of that stream by the Mississippi River in pre-Wisconsin time. Glacial outwash of Wisconsin age in the valley floor indicates that the trench was reoccupied during Wisconsin time by a part of the Mississippi River and later abandoned again. At present the poorly drained valley is occupied only by a northward-directed spring-fed creek, and by the insignificant southeastward-flowing Couler Creek.

A second example of stream rearrangement is in Tps. 28 and 29 N., R. 4 E., in Illinois. In pre-Illinoian time, the present Apple River and its tributaries and branches comprised two stream systems. One of these systems drained the area containing that part of the modern Apple River and its tributaries which lies

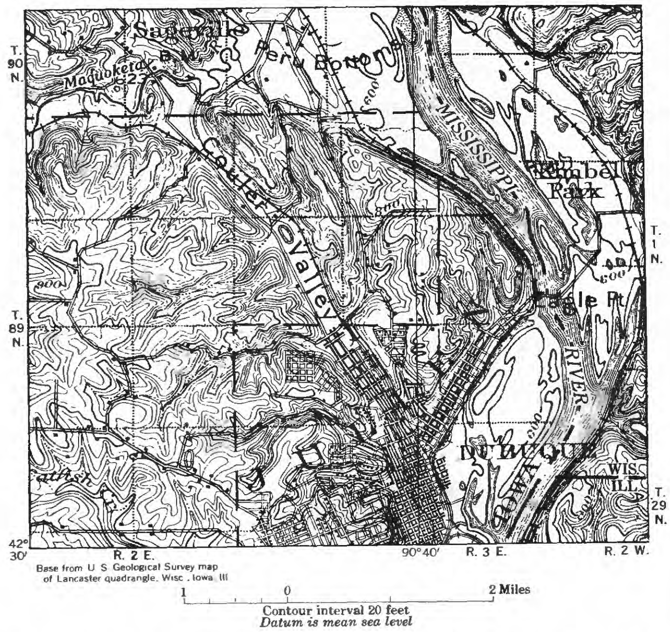


FIGURE 10.—Map showing Couler valley, an abandoned channel of the Little Maquoketa and Mississippi Rivers. The Little Maquoketa River is the northeastward-flowing stream shown in the upper left part of the map, and the Mississippi is the large river shown in the east half of the map.

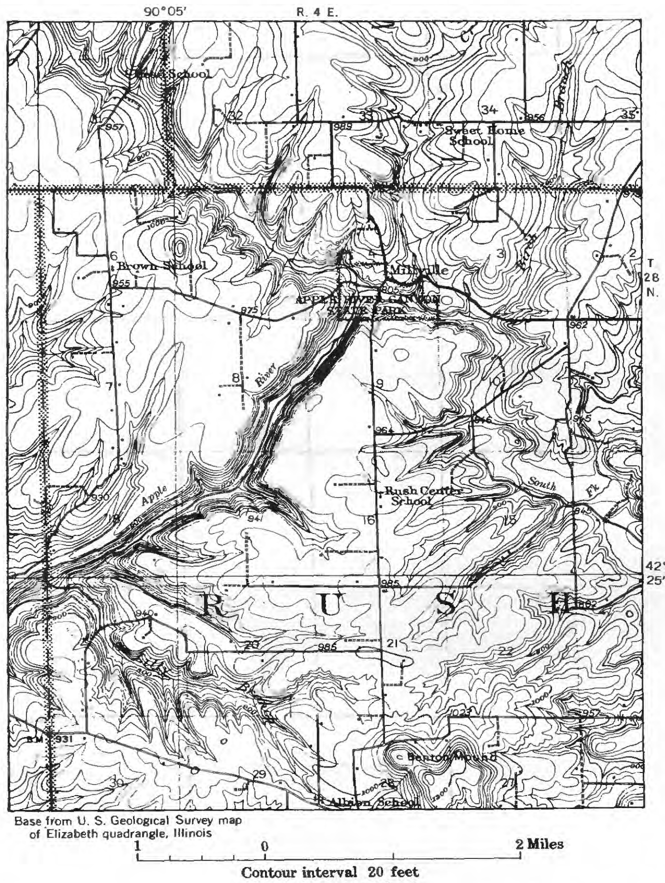


FIGURE 11.—Map showing Apple River piracy, about 9 miles north from Stockton, Ill.

southwest of the head of Apple River Canyon (fig. 11). The second stream system served the area drained at present by the West and South Forks of Apple River and their branches, plus a considerable area to the southeast. The master stream of this second system flowed toward the southeast before it was damned by the encroachment of one of the ice sheets, probably the Illinoian, and a temporary glacial lake occupied the valley. Normal drainage, augmented by glacial melt waters, raised the surface of this lake until it overflowed the divide which separated the two stream systems, and the discharge of the ponded waters eroded rapidly the deep, steep-walled Apple River canyon. The direction of flow in the stream which occupied the valley of the present South Fork was reversed, and the South and West Forks join the main Apple River at a conspicuous T-juncture in Apple River Canyon State Park, Ill.

TERRACES

DEPOSITIONAL TERRACES

Terraces occupy parts of the major stream valleys in the district and have been grouped into "high-level" and "low-level" terraces; the low-level terraces are more abundant and more easily recognized.

As seen in the field, low-level terraces along both of the major streams in the district and along their larger tributaries are not prominent topographic features. These terraces are composed of heterogeneous gravels and stratified sand and clay, and are as much as 55 feet above the flood plains. The terraces remain in protected areas in the Mississippi River gorge, along the Wisconsin River, and for several miles upstream from the mouths of larger tributaries. The sand and gravel are glaciofluvial material, for the most part of Wisconsin age. The terraces occupy only a small part of the valley flats and are commonly discontinuous elongate, narrow features which lie at the base of the river bluffs. Examples of these features are found in the City of Dubuque and at Guttenberg, Iowa, and at Cassville, Bagley, and Prairie du Chien, Wis. The terraces at Dubuque and at several places north of the district are 45 feet above the flood plain of the Mississippi River. At Guttenberg, Cassville, Bagley, and Prairie du Chien the upper surfaces of lower terraces are only 20 to 30 feet above the flood plain. Thus, two lower terraces, one at about the 25-foot level and the other at the 45- to 55-foot level represents the low-level terrace group in the district.

The lower terraces are all constructional, and are the remnants of an older valley fill deposited before rejuvenation caused the rivers to erode in their channels.

In addition to those composed of glacial drift, other low-lying terraces of locally derived alluvium are present in all the larger valleys tributary to the Mississippi and Wisconsin Rivers. The dumping of glacial material by the overloaded main streams aggraded their beds and caused ponding of their tributaries, which in turn readjusted gradients by depositing in their channels. Subsequent rejuvenation produced the alluvial terraces in the lower reaches of the stream valleys in the same manner as the terraces in the major stream valleys were formed. The low-level terraces were all deposited during Wisconsin time.

High-level terraces, which stand from 100 to 125 feet above the flood plain, are along the bluffs of the Mississippi Valley. The terraces are poorly defined and are represented essentially by patchy deposits. They are composed of moderately iron-stained gravels containing subrounded quartzite, quartz, and chert pebbles, all of which are commonly smaller than 1 inch in diameter.

Examples of these high-level gravels are situated as follows:

1. Secs. 11 and 14, T. 87 N., R. 4 E. (Iowa).
2. Near Blanding, Ill., and 4 miles southeast. T. 26 N., R. 1 E.
3. 1½ to 2 miles southeast of Cassville, Wis. Sec. 22, T. 3 N., R. 5 W.
4. On the Bridgeport rock terrace in the Wisconsin River valley near its juncture with the Mississippi Valley. Secs. 1, 8, 9, 10, 11, and 12, T. 6 N., R. 6 W.
5. East and west of Wauzeka, Wis. T. 7 N., Rs. 3, 4, 5 W.

All these deposits were emplaced in pre-Illinoian time and are possibly correlatives of the Buchanan gravels of Kansas age in eastern Iowa.

EROSIONAL TERRACES

The Bridgeport rock terrace, mentioned above, is the best example in the mining district of the erosional- or cut-terrace form. This rock terrace rises 130 to 160 feet above the flood plain along the Wisconsin River near its juncture with the Mississippi. Its surface marks the top of the resistant dolomite of the Prairie du Chien. The removal of the overlying weaker St. Peter sandstone by erosion has left this moderately flat area on which are patches of drift and a mantle of loess. Elsewhere smaller erosional terraces are present locally in the bluffs of the Mississippi and Wisconsin Rivers.

CAVES AND SINKS

Natural caverns are fairly common in the district within a few formations, though they are relatively small. These caves originated by solution of carbonate strata during circulation of vadose and phreatic waters down and along joints. Some of the early lead mining in the district was directed toward the recovery of galena which was found in small caves, and weathered zones along joints above the water table. This relationship plus a remarkable similarity between the joint-controlled pattern of many of the caves and the typical cross-joint pattern of some of the "crevice" systems in which galena was deposited indicates that the caves were formed along joints in the zone of weathering.

Large and numerous caverns have been formed in dolomite of the Prairie du Chien group, but caves are known in the Galena dolomite of Ordovician age and also in the dolomites of Silurian age. A tabulation of the larger and better known caves is given below.

Caves in the district

Name	Location	Size, in feet		
		Length	Width	Height
Cave of the Mounds	1 mile east of Blue Mounds, Wis.	1,000	6–15	6–30
Eagle Cave	6 miles northeast of Blue River, Wis., NW¼ sec. 19, T. 9 N., R. 1 E.	960	70	7½
Bear Cave	6½ miles northeast of Boscobel, Wis., NW¼NE¼ sec. 28, T. 9 N., R. 1 E.	800	7–60	5–40
Kickapoo Cave	Northwest of Wauzeka, Wis., NW¼ sec. 10, T. 7 N., R. 5 W.			
Crystal Lake Cave	4½ miles southeast of Dubuque, Iowa, SW¼ sec. 16, T. 88 N., R. 3 E. (Ia.).	650	9	3–15
John Gray Cave	7 miles northwest of Richland Center, Wis., SE¼NW¼ sec. 25, T. 11 N., R. 1 E.	710	7–60	5–40

Of these caverns, only the Cave of the Mounds and Crystal Lake Caves are in the Galena dolomite; the others are in the Prairie du Chien group.

Sinkholes are common in parts of the district. Their origin is similar to, and closely associated with, that of the natural caverns. For the most part the sinks have an elliptical outline; they may have a long dimension greater than 200 feet and a depth of more than 30 feet. Commonly their size is a function of the particular strata in which they are formed; the large sinks occur in the northern part of the district where the Prairie du Chien group is exposed, and in the upland areas in the southern part of the district where the dolomite of Silurian age is exposed. The sinks in the Silurian average about 100 feet in diameter and are 20 to 25 feet deep. Sinks in the Galena and Decorah formations are much less abundant. However, in Iowa, these formations contain an increasing number of sinks northwest of Prairie du Chien, Wis., where the strata become more calcareous. Most of the sinks in the district are dry, but in a few places they contain ponds. Some of the larger sinks in the district are listed in the following table.

Larger sinkholes in the district

Name	Location	
South edge of East Blue Mound.	SW¼, sec. 5, T. 6 N., R. 6 E.	Dane County, Wis.
2 miles west of Mifflin	SE¼SW¼ sec. 32, T. 5 N., R. 1 E.	Iowa County, Wis.
½ mile west of West Platte Mound	NW¼ sec. 6, T. 3 N., R. 1 E.	Lafayette County, Wis.
1½ miles northeast of Meekers Grove.	SE¼SE¼ sec. 15, T. 2 N., R. 1 E.	Do.
½ mile south of Rewey	SE¼NW¼ sec. 8, T. 4 N., R. 1 E.	Iowa County, Wis.
2½ miles northeast of Darlington.	SW¼SW¼ sec. 19, T. 3 N., R. 4 E.	Lafayette County, Wis.
3 miles south of Blanchardville	NE¼SW¼ sec. 1, T. 3 N., R. 5 E.	Do.
1 mile west of Fennimore	NW¼NE¼ sec. 24, T. 6 N., R. 3 W.	Grant County, Wis.
3 miles east of Stitzer	NW¼NE¼ sec. 16, R. 5 N., R. 1 W.	Do.
2 miles northeast of Benton	NW¼SW¼ sec. 2, T. 1 N., R. 1 E.	Lafayette County, Wis.
2 miles north of Blanding	Several in the center of sec. 27, T. 27 N., R. 3 E.	Jo Daviess County, Ill.
1½ miles southeast of Woodbine.	SE¼ sec. 14, T. 27 N., R. 3 E.	Do.

STRUCTURE

GENERAL FEATURES

The structural features of the upper Mississippi Valley zinc-lead district are of interest, because of (1) the excellence of the district as an example of an area that was never structurally developed beyond initial stages of deformation, (2) the unusual fault and crossfold systems that are apparently related to similar larger structures in the surrounding region, and (3) the marked control that the gentle folds, minor faults, and joints had exercised on the localization of the ore deposits.

Regionally the zinc-lead district is southeast of the Wisconsin dome and on the gentle west limb of the Wisconsin arch. To the south is the Illinois basin, and to the west and southwest the Forest City basin. A few miles south of the district in Illinois is the westward-trending Savanna-Sabula anticline, which branches off from the Wisconsin arch near Oregon, Ill.

Crossing the district in a general westerly direction north of the Savanna-Sabula anticline are two other anticlines of about the same magnitude. The three folds described are all asymmetric with steeper north limbs. The regional strike within the district is approximately N. 85° W., and the dip is south, at about 18 feet per mile. In the northwestern part the strike changes to about N. 45° W., but the dip remains approximately the same.

Although major faults are rare and are located with difficulty, both reverse and shear faults have in places been traced for several miles.

The smaller geologic structures are similar to those found in places elsewhere in the North Central states, consisting of gentle crossfolds, numerous faults of small displacement, and a well-defined system of joints. Plates 2–7 show the detailed areal and structural geology of six areas selected for their particular geologic and economic interest.

The smaller folds, which like the major anticlines differ in trend from place to place, fall into two groups: a principal one trending east to northeast, and a less important group trending northwest. These lesser folds are commonly elliptical in outline. Owing to a progressive decrease in the intensity and magnitude of folding from south to north, the folds are much more closely spaced and have greater amplitudes in the southern part of the district.

The structures of greatest economic and genetic interest are the folds and the associated fracture systems. The significant fracture systems—reverse and bedding-plane faults of small displacement, and inclined joints—are on the flanks of the folds. The fracture zones are traceable for as much as 5 miles along their strike and commonly follow the flanks of the folds. In places the mineralized shear zones curve around the axial noses of the folds to form arcuate rims.

A well-defined system of vertical joints is prevalent throughout the district. Many of these joints contain deposits of lead minerals, or less commonly zinc and copper minerals. Single joints have been traced for well over a mile along their strike.

In the following pages the geologic structures of the district and the surrounding region are described, beginning with the major structures of the North Central States and finishing with the smallest structures that are factors in the control of the mineral deposits. Following these descriptions is a discussion of the origin and mode of formation of the structures. Although the types and general theory of origin of the geologic structures that control the ore bodies is discussed, the details of the structures of the ore bodies are described in a later section under "Ore deposits".

REGIONAL RELATIONS

The structures of the North Central States (fig. 3) are listed below in the order of their magnitude and are grouped according to their interdependence. In order to avoid the confusion resulting from discussing these seven orders in detail, the system shown in the right column is used in this report.

Regional names	*Names used in this report*
1. Precambrian shield	Precambrian shield.
2. Wisconsin dome, Illinois basin, Forest City basin, Michigan basin. 3. Wisconsin arch, Mississippi River arch, Kankakee arch, Cincinnati arch.	Major structural features.

Regional names	*Names used in this report*
4. Savanna - Sabula anticline, Oregon dome, Meekers Grove anticline, Mineral Point anticline.	First-order folds (within district), also major faults.
5. Intermediate flexures	Second-order folds, also minor faults.
6. Minor flexures	Third-order folds, also minor faults.
7. Joints	Joints.

The relation of the upper Mississippi Valley zinc-lead district to the surrounding structural features is shown on figure 12. The district is about 100 miles south of the north edge of the nearly flat-lying Paleozoic sedimentary rocks that rest upon the Precambrian rocks in northern Wisconsin. The Wisconsin dome, which exposes the basement of crystalline rocks in northern Wisconsin, has been a stable positive area since Precambrian time.

A number of major structural features involving rocks of Paleozoic age have been developed near this dome in the upper Mississippi Valley (fig. 12). The most important of these major structural features are (1) the Forest City basin to the west, (2) the Illinois basin to the south, and (3) the Michigan basin to the east. A major crustal arch extends from the Wisconsin dome south into central and southern Illinois. The axis of this uplift is about 60 miles east of the center of the district. The part in Wisconsin and northernmost Illinois is called the Wisconsin arch. To the south in northern Illinois is the Oregon dome, a small area of relatively strong uplift that is also the focal point for numerous surrounding structures (fig. 12). Southward from the Oregon dome the continuation of the Wisconsin arch is known as the LaSalle anticline, which extends southeastward into the Illinois basin and divides the northern part of that basin into two subbasins.

Another low northward-trending flexure, comparable to the Wisconsin arch, lies between the Illinois and Forest City basins along the Mississippi River (Howell, 1935, p. 386–389). Possibly related to this Mississippi River arch is the Savanna-Sabula anticline, in northern Illinois, which trends nearly east but curves southward at its east and west ends. It intersects the Wisconsin arch at the Oregon dome, and perhaps meets the Mississippi River arch in the region northwest of Davenport, Iowa. The Savanna-Sabula anticline has a structural height of about 200 feet and its steeper limb is to the north.

A similar asymmetric anticline has been described in Allamakee County, Iowa (Calvin, 1895, p. 86–88). The Allamakee anticline trends northwestward and is parallel to the northeastern border of the Forest City basin. The Allamakee anticline is of the same order of magnitude as the Savanna-Sabula anticline and likewise is asymmetric, with its steeper northeast limb toward the Wisconsin dome.

Two other eastward-trending major anticlines cross the axis of the Wisconsin arch (figs. 12 and 13) in south-central Wisconsin. In the eastern part of the district the beds along the northern flank of each of these flexures are dropped down a distance of at least 100 feet. This drops probably is due to a combination of folds and faults. However, Thwaites (oral communication, October 1945) has expressed the opinion that the depressed blocks are bounded along their southern sides by simple normal faults, similar to the fractures which have been interpreted by him as normal faults within the steeper eastern limb of the Wisconsin arch. Two important anticlines of the mining district are probably the westward continuations of these flexures.

STRUCTURES OF THE MINING DISTRICT

The upper Mississippi Valley mining district (marked by the square in the center of fig. 12) is on the gentle western limb of the Wisconsin arch. In general the rocks of the district dip southward at a very low angle, but this regional dip is interrupted by complex but very gentle folds. The regional strike within the area averages N. 85° W., and the dip toward the south is about 18 feet per mile. Along the west and northwest fringes of the district this regional strike swings to N. 45° W., but the rate of dip, from here to the southwest, remains about the same. From this relation it is apparent that in the main part of the district the regional southward dip component from the Wisconsin dome predominates over the westward dip component produced by the Wisconsin arch.

Structurally the upper Mississippi Valley zinc-lead district is an uplifted, gently sloping area bounded by the Wisconsin dome on the north, the Wisconsin arch on the east, the Savanna-Sabula anticline on the south, and the Forest City basin on the west (fig. 12).

FOLDS

Within the district the Paleozoic rocks have been very gently folded into broad complex anticlines and synclines (pl. 8), which can be grouped in three orders of magnitude. The longest first-order folds in Wisconsin (the Meekers Grove and Mineral Point anticlines) are at least 40 miles long, and from 3 to 6 miles wide, with amplitudes as much as 200 feet.[11] Second-order flexures between the major folds, or superimposed upon them, have amplitudes from 40 to 100 feet. These folds tend to be linear in pattern, and average more

[11] Amplitude is defined as the total vertical distance between the crest and trough of the folds, and this definition will be used hereafter.

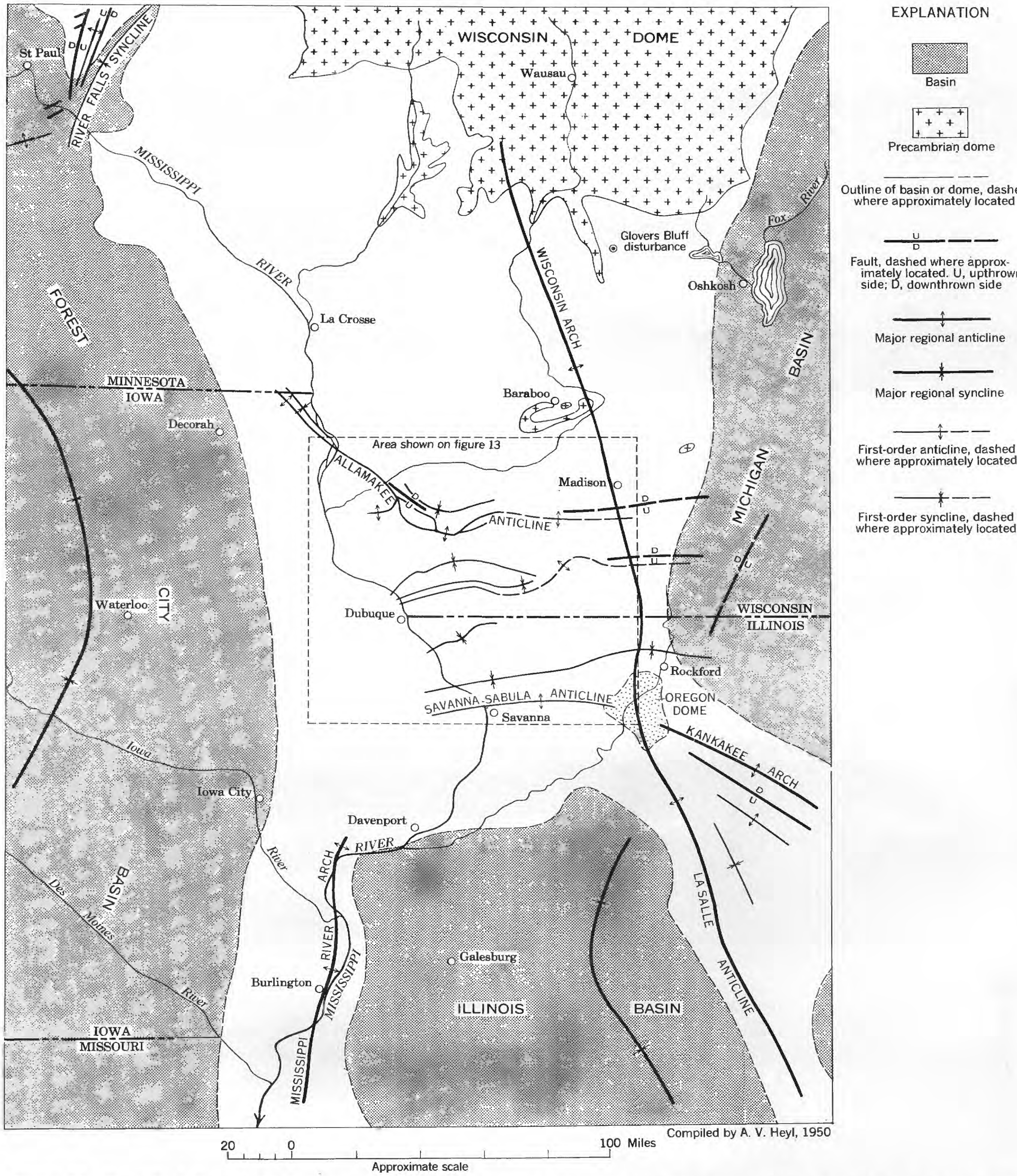


FIGURE 12.—Generalized diagram showing the major structural features of the region bordering the upper Mississippi Valley district (shown by the central square area), and their relations to the principal structures within the district itself.

than 10 miles in length. The third-order folds range from those having a linear extent from 1 to 2 miles and a vertical amplitude from 20 to 60 feet, down to little crumples 100 feet long, 10 to 15 feet wide, and from 1 to 3 feet in amplitude. These third-order folds are generally shallow and open, the dips on the limbs being rarely more than 15° and more often ranging from 1° to 5°. The fold axes plunge and rise along their lengths owing to crossfolds and thus form a chain of connected saddles, basins, and domes. All the larger anticlines are asymmetric with the steeper limbs to the north (pl. 8). The magnitude of the folding decreases markedly from south to north throughout the area.

FIRST-ORDER FOLDS

The position and trend of the axes of the first-order folds of the district are shown as the heavy lines in figure 13. The major folds in the southern part of the district have generally east and northeast trends, but those in the northern part exhibit extremely variable

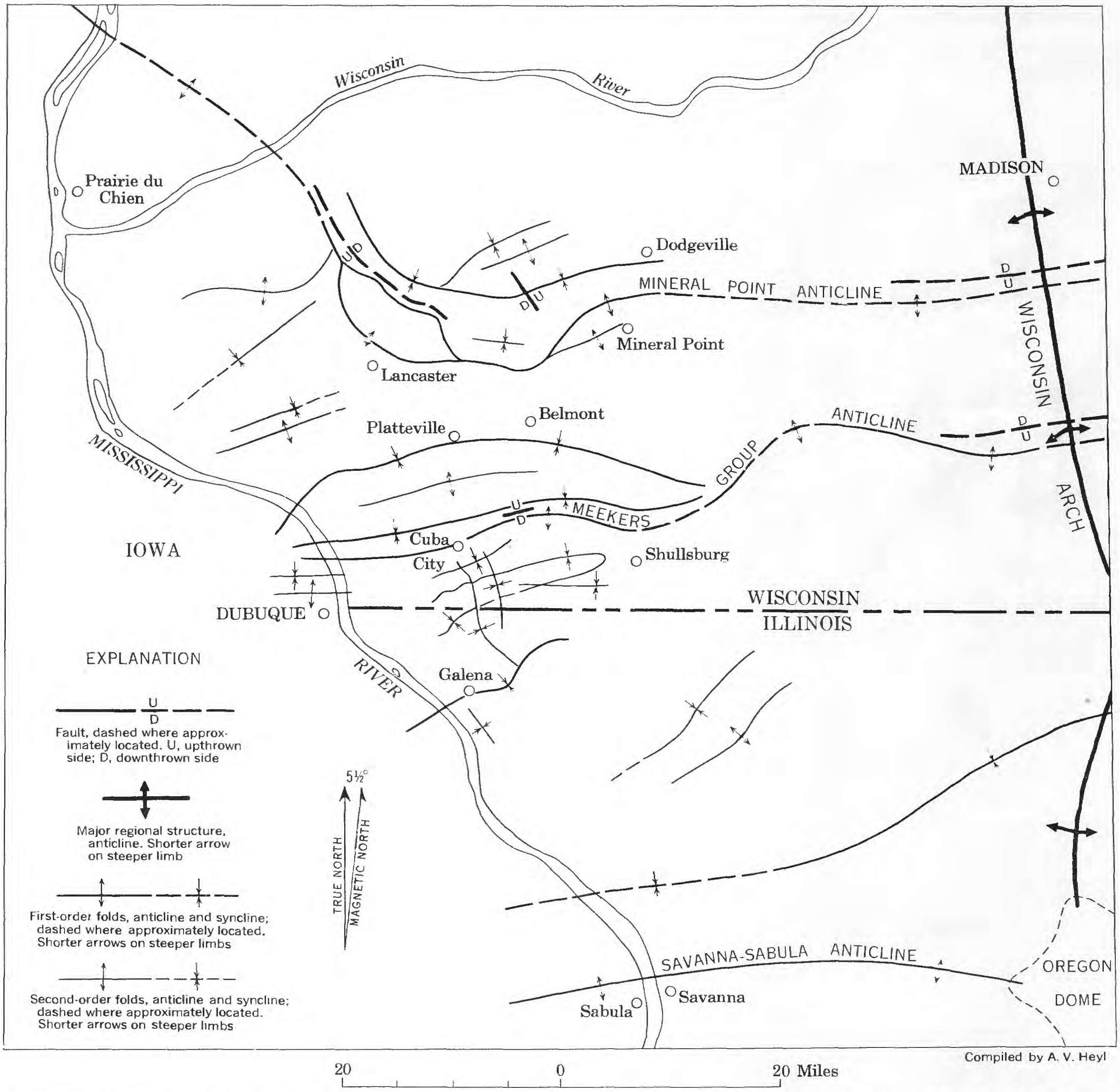


FIGURE 13.—Axial trends of the larger folds and faults in the Upper Mississippi Valley district. First-order folds are shown as heavy lines; second-order folds as light lines; faults as hachured lines. Hachures mark the down-thrown side. Short arrows indicate the steeper limbs of the folds.

trends swinging from southwest in the eastern part of the district, through west to generally northwest trends in the western part of the district.

The upper Mississippi Valley district is divided structurally by three first-order anticlines into three parts. Within each part, the magnitude of the folds is fairly uniform (fig. 13). The largest and most abundant folds are in that part of the area between the Savanna-Sabula anticline, at the south edge of the district, and the Meekers Grove anticline to the north; the smaller folds are in the part between this first-order anticline and the Mineral Point anticline still farther north, and the folds of least magnitude are north of the Mineral Point anticline.

The Meekers Grove anticline (pl. 8 and fig. 13) extends from a point north of Dubuque, Iowa, eastward through Cuba City, Wis., to a point a short distance north of Shullsburg, Wis. The general due-east trend is modified, however, by a sharp northward curve near Cuba City, and by another curve southward just north of Shullsburg (pl. 3). The fold ranges in amplitude between 100 and 200 feet. The width of the anticline is from 3 to 5 miles, and the north limb dips much more steeply than the south limb along the entire length. Immediately to the north and parallel to the Meekers Grove anticline is the sharp asymmetrical first-order Georgetown syncline. Figure 14 illustrates in detail the structure of a part of this anticline 5 miles east of

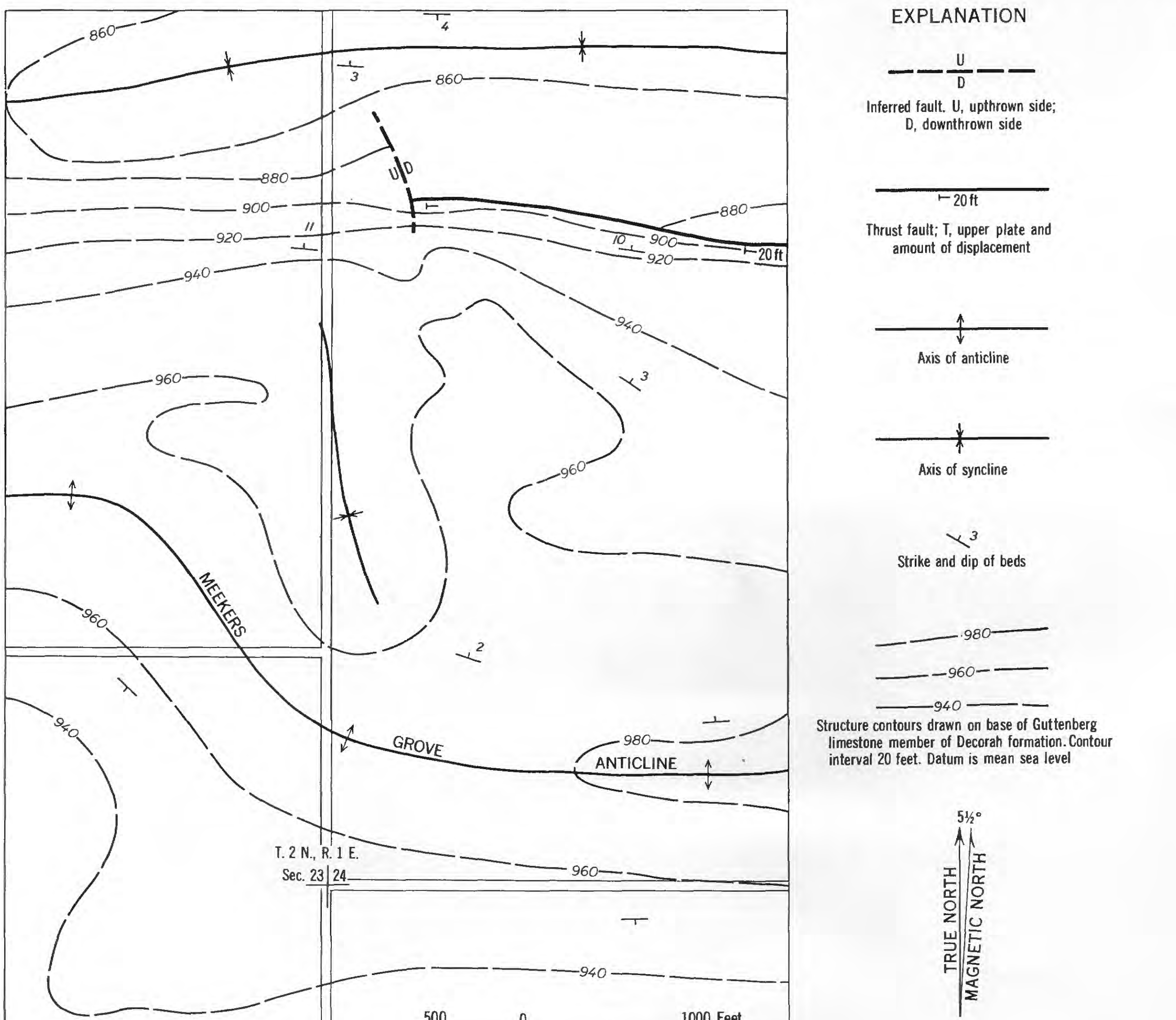


FIGURE 14.—Structure map of folds and faults in the E½, sec. 23, W½, sec. 24, T. 2 N., R. 1 E., 2 miles east of Meekers Grove, Wis. Axial trends of first-order folds are shown with heavy lines. Meekers Grove anticline crosses the central part of the area. Note the thrust fault in the northeast part of the area on the north limb of the anticline. Contour interval, 20 feet.

Cuba City, Wis., near Meekers Grove. The figure shows the broad crest of the anticline, with the short, steeper north limb. Some third-order crossfolds overlap larger folds, and a major thrust fault cuts the steeper north limb of the Meekers Grove anticline.

The Mineral Point anticline, in the northern part of the area shown on plate 8 and figure 13, is a complexly curved fold that extends southwestward from Mineral Point, Wis. East of Lancaster, Wis., it splits and turns northwestward. Like the Meekers Grove anticline this fold is asymmetric with a much steeper north limb and is also paralleled to the north by the marked asymmetric first-order Annaton syncline. A major thrust fault along the northwestern part is on the steeper north limb of the anticline (pl. 8 and fig. 13). The amplitude of the anticline is between 100 and 170 feet and, because the anticline branches, its width ranges from 5 to 8 miles.

The Mineral Point anticline changes its trend through almost 90° from one end to the other. Thus it forms a great arc, convex toward the southwest, which partly encloses the northern part of the mining district. The eastern end of this anticline near Mineral Point, Wis., has a general southwest trend parallel to the axes of the most common group of second-order folds in the district. The western end has a northwest trend parallel to the numerous northwestward-trending lesser flexures in the district. A first-order syncline closely parallels the Mineral Point anticline on its northward side. The area to the northeast of these folds exhibits the least degree of deformation in the entire district.

A less prominent fold, with a traceable length of 42 miles, is the Platteville syncline extending from the sharp westerly curve of the Mississippi River north of Dubuque, Iowa, northeastward to Platteville, Wis., and thence eastward curving to the southeast toward the east end of the Meekers Grove anticline. This gentle open syncline has a northerly axial bow and is less asymmetric toward the north than the previously described folds.

The orientation of the axes of all the first-order folds in the district is shown in figure 15. The most common axial trends are toward the east. Some of the axes trend northwestward, N. 50° W. being most common. In the eastern part of the district, the axes of some of the first-order folds have a northeasterly bearing. The changes of the axial trends of the first-order folds in the west half and east half respectively of the district are indicated in figure 16. The predominant axial trend in both parts is eastward, but it ranges from due east in the west half of the district to slightly

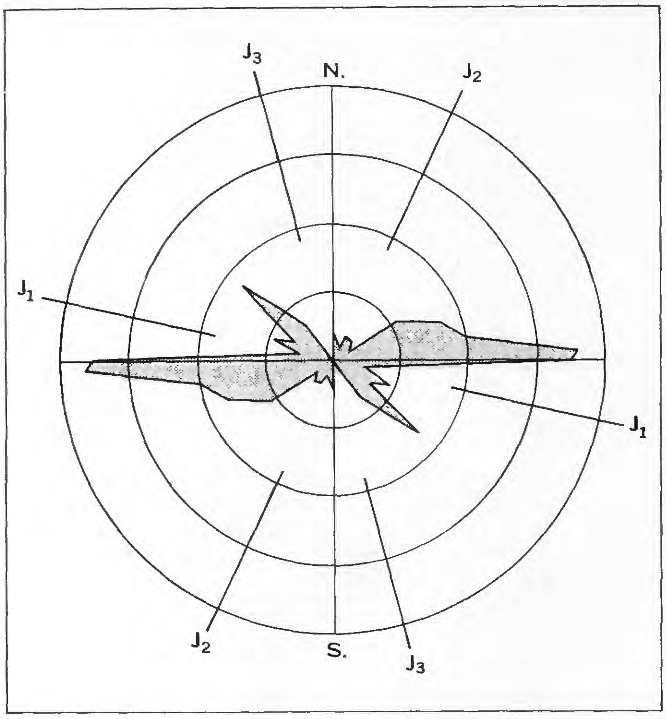


FIGURE 15.—Diagram showing the axial-trend relations of the first-order folds in the district, including the Savanna-Sabula (Ill.-Iowa) and Allamakee (Iowa) anticlines. Each circle indicates a 25-mile length of folds. Heavy radiating lines indicate the average trends of the three major groups of vertical joints throughout the district.

north of east in the east half. Folds of northeast trends are fairly common in the east half and much less so in the west half, whereas folds trending N. 50° W. are fairly common toward the west half of the district and are rare in the east half of the district.

SECOND-ORDER FOLDS

The structure in the low, broad areas between the first-order anticlines, and in part superimposed upon them, is marked by secondary folds ranging in length from 3 to 12 miles and having a width of about a mile (pl. 8 and fig. 18). These folds, in turn, are modified by numerous still-smaller third-order folds. The second-order folds, like their larger counterparts, consist of a connected series of gently plunging anticlines and synclines of elliptical outline. In general they are fairly symmetrical, but many of these secondary folds have distinctly steeper northern or northeastern limbs. Figure 17 illustrates diagrammatically the relations of all the second-order fold axes in the Hazel Green-Shullsburg area (pl. 5) of 50 square miles. The axes of the second-order folds in this area and throughout the district tend to fall into three divergent axial groupings:

Trends of Second-order fold axes

Group	*Trend*	*Comments*
A	N. 50° E.	Some axes diverge towards due east.
B	Due east.	
C	N. 10°–40° W.	N. 30° W. is the most prevalent trend.

Figure 18 illustrates parts of two of these second-order folds. One of them trends N. 30° W., and the

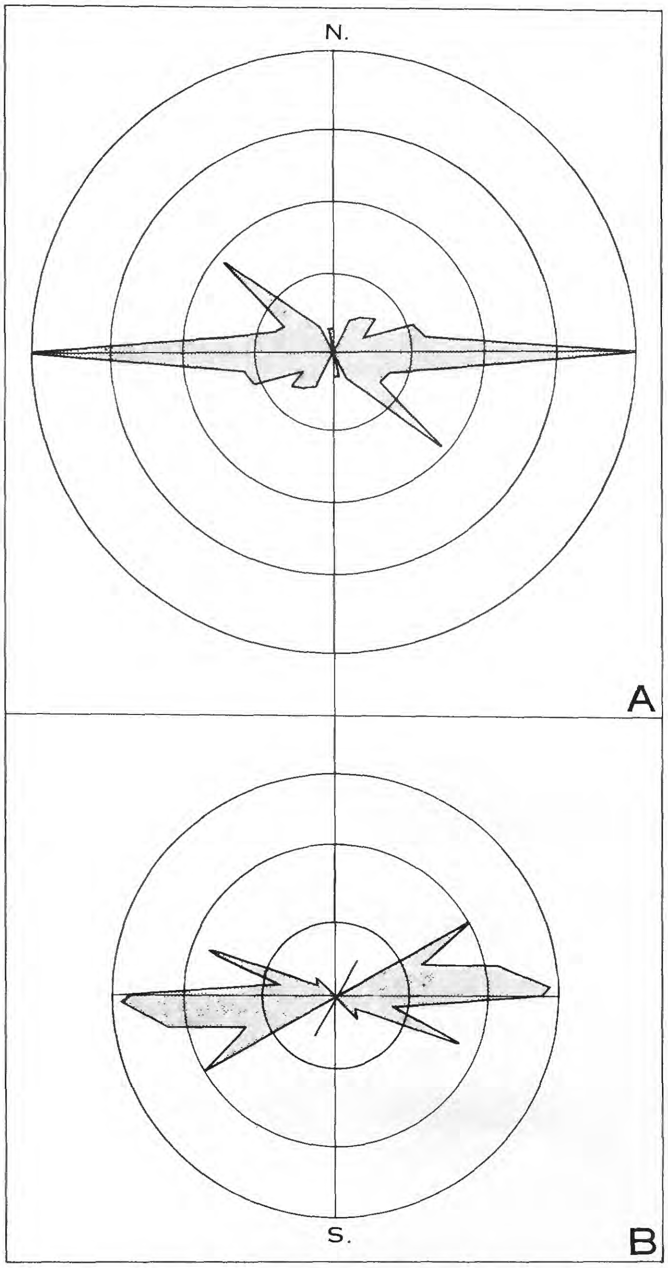


FIGURE 16.—Diagrams showing the axial-trend relations of the first-order folds. *A*. In the west half of the district. Each circle indicates a 10-mile length of folds. Note the prominent northwestward-trending fold group. *B*. In the east half of the district. Note the increased prominence of the N. 60° E. folds and the lesser importance of the northwest folds.

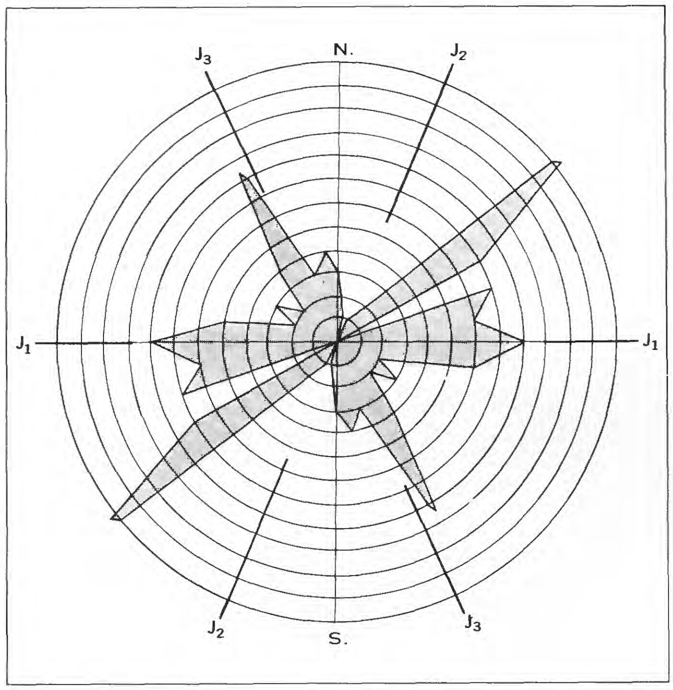


FIGURE 17.—Diagram showing the axial trend relations of second-order folds in the Hazel Green-Shullsburg area. Each circle indicates a 1-mile length of folds. Note prominent northeast and northwest fold groups. Heavy radiating lines indicate the average trends of vertical joint groups in the area.

other has a N. 60° E. average trend nearly at right angles to the first. Commonly the axes of the northwestward-trending folds are relatively straight whereas those with northeasterly trends exhibit sharp local variations in direction owing to intersections with third-order folds. Both second-order folds exhibit local rises and plunges of the fold axes that are due to minor crossfolding. A notable feature of some of these second-order folds in the district is the alinement of many of the known zinc ore bodies along them; this is particularly true of the synclinal structures, as is also shown in figure 18.

In many parts of the district the northeastward- and northwestward-trending sets of second-order folds are of equal abundance and magnitude, as shown in figure 18. In other parts, however, one trend is dominant over the other. For example, in that part of the district in northern Illinois to the south of Hazel Green, Wis. (pl. 8; and Willman and Reynolds, 1947, pls. 1 and 7), the northwestward-trending folds are dominant in size and number. Eastward from Hazel Green, as shown in plate 5, the northeastward-trending second-order folds become increasingly dominant features, and the northwestward trending folds decrease in number and size, so that about 10 miles to the east they are of very local occurrence. In this eastern area, however, several second-order folds bearing nearly due east are present

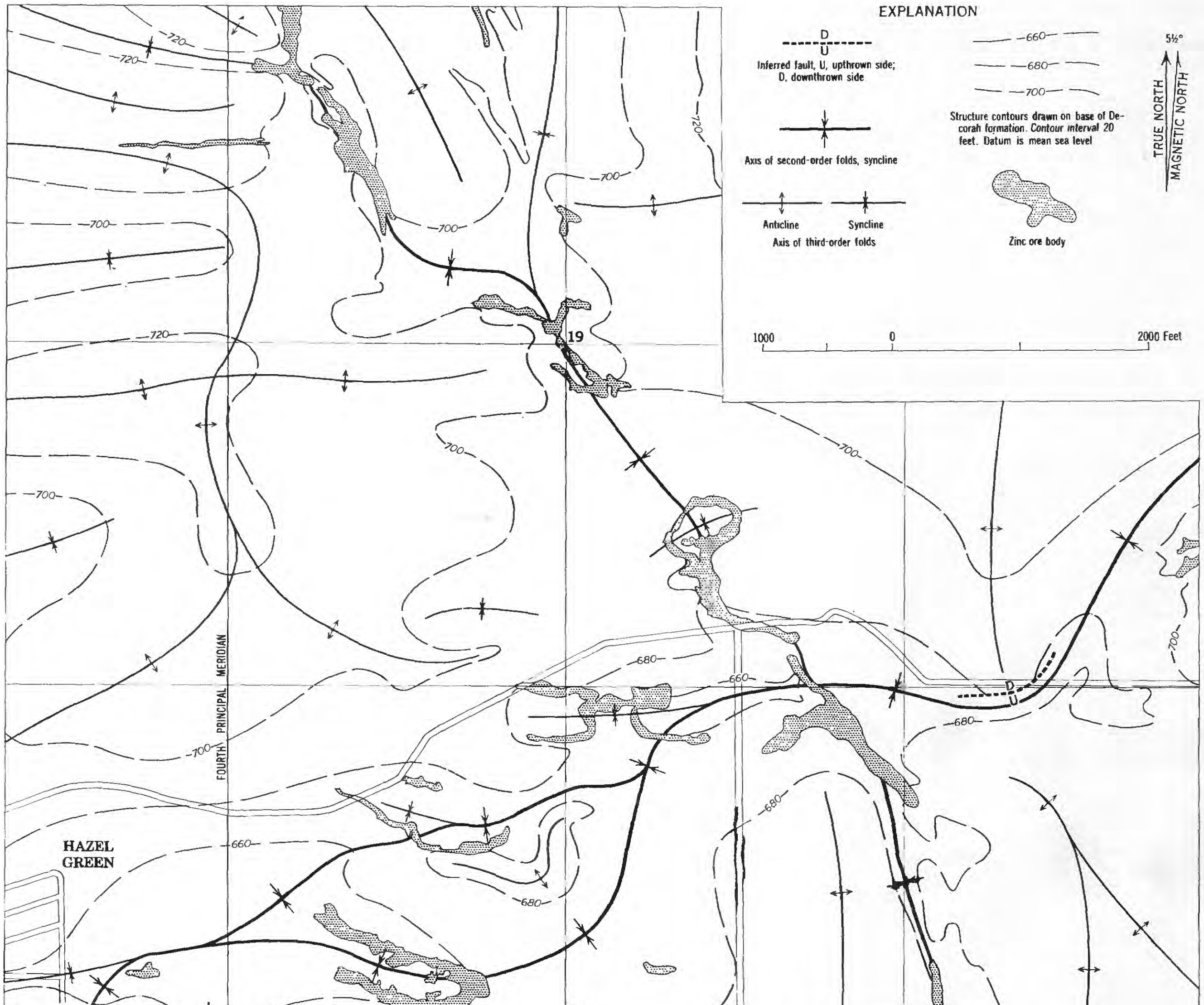


FIGURE 18.—Structure map of the area east of Hazel Green, Wis. Second-order and third-order folds with related zinc ore bodies illustrate intricate crossfold patterns and interrelationships of ore bodies and folds. Contour interval 20 feet.

in addition to the northeast-trending flexures previously described. The area near Shullsburg is characterized by these two trends of intermediate folds and by third-order flexures with similar bearings. This variation in direction of dominant second-order folds prevails throughout the entire district. Northeastward- and eastward-trending second-order folds are apparently more abundant in the eastern half of the district, which is nearer the northern rim of the Illinois basin, and northwestward-trending flexures become more abundant in the western half of the district which is closer to the east edge of the Forest City Basin.

THIRD-ORDER FOLDS

Many third-order folds or flexures are superimposed upon the larger structures. The axes are generally from 1 to 2 miles in length, and the amplitudes are from 20 to 60 feet. These flexures, like their larger counterparts, may be classified into three groups according to general axial trend: due east, which is most common; northwest, of second importance; and northeast, least common (fig. 19). These folds show much greater variation in axial bearings than the larger folds, and many exhibit curved axial lines. However, the three major groups of fold trends are recognizable in the minor folds as shown in figure 18, which illustrates a number of these third-order folds that intersect the second-order folds and lie in the intervening areas. Many of the zinc-ore bodies lie within these minor folds and particularly, although not necessarily, in those flexures lying along or crossing the second-order folds.

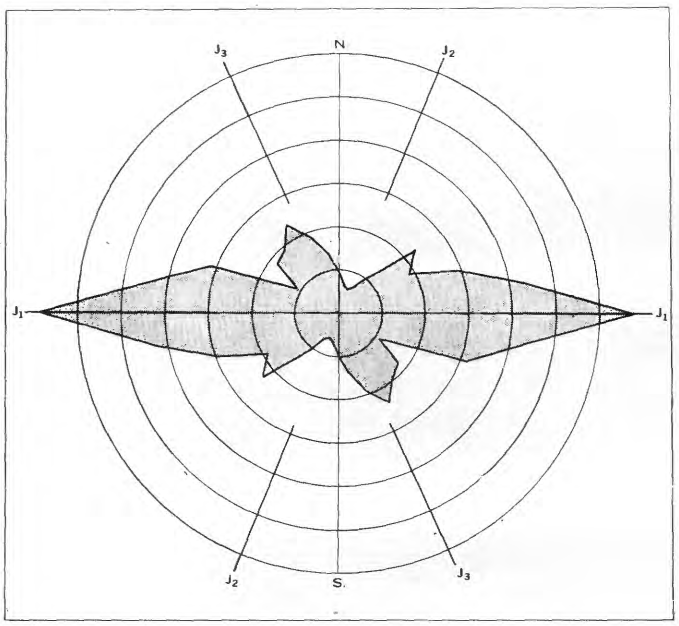


FIGURE 19.—Axial trend relations of the third-order folds in the Hazel Green-Shullsburg area. Each circle indicates the trend of 10 folds. Heavy radiating lines show the average trends of the principal joint groups. Includes 323 folds.

Owing to the prevalent crossfolding, the third-order folds are commonly short in axial length and are typical domes and basins of elliptical outline with a ratio of one unit in width to three in length. These are the typical "canoe-shaped" basins and domes mapped by Grant (1906, p. 53–54, pls. 1–18), Bain (1906, p. 35–45, pls. 8–15), and Cox (1914, p. 34–35, pls. 20–21). Monoclinical folds are fairly common on the limbs of larger folds. Like the larger folds, the third-order flexures decrease in magnitude and amplitude from south to north throughout the district, commencing with closely spaced flexures of about 50 feet in amplitude in the southern part of the district and diminishing to widely spaced, very gentle flexures of 10 to 20 feet in amplitude in the northern part of the district.

The third-order flexures reflect the same general range of axial trends as the larger folds. Figure 19, as previously mentioned, illustrates the axial orientation of the third-order flexures in the Hazel Green-Shullsburg area (fig. 19). In figure 20 the data have

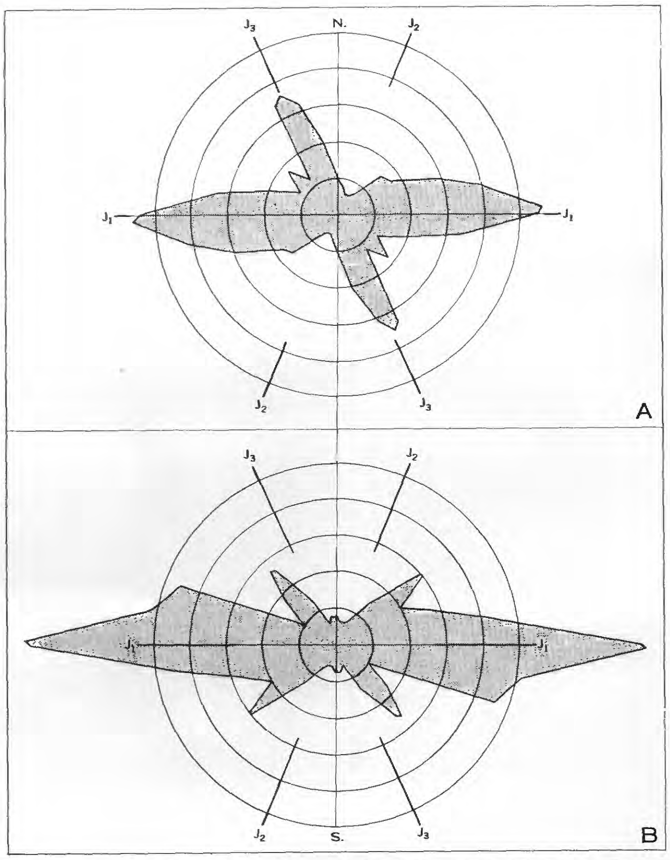


FIGURE 20.—Axial-trend relations of the third-order folds. *A*. In the west half of the Hazel Green-Shullsburg area. Note the prominence of northwestward-trending folds. Each circle indicates 5 folds. Heavy radiating lines indicate the average trends of the major vertical-joint groups. *B*. In the east half of the Hazel Green-Shullsburg area. Note the decreased importance of northwestward-trending folds and the increased importance of the northeast folds. Heavy radiating lines indicate the average trends of the major vertical-joint groups.

been divided between the east and west parts of that area, and the diagrams illustrate the difference in relative abundance of the fold axes of the three general directions in the two parts of this area. In both parts of the Hazel Green-Shullsburg area the east-trending third-order folds are predominant but northwestward- and northeastward-trending folds also are present. In the west half of the area (fig. 20*A*) the northwestward-trending flexures are far more common than the northeastward-trending flexures, whereas in the east half of the area (fig. 20*B*) the northeastward-trending folds form a divergent trend and are slightly more abundant than the northwestward-trending folds. This general relationship is fairly well established elsewhere throughout the southern half of the entire district, and from the data available it is probably applicable in the northern half of the district as well.

SUMMARY OF FOLDS

The folds of the upper Mississippi Valley district are very broad and open. They are divisible into three groups according to their orders of magnitude. Those folds having generally east trends are predominant, but crossfolds of northeast and northwest trends are common. The northwestward-trending folds are most abundant in the west half of the district (fig. 16*A*), and the northeast-trending folds are more abundant in the east half (fig. 16*B*). All the folds decrease in intensity toward the north and commonly have steeper northward limbs.

FAULTS

Faults are numerous in the district, and most of them show displacements of less than 10 feet. A few of the measurable total displacements range from 20 to 60 feet, and in at least one place the horizontal component of displacement alone may be as much as 1,000 feet (pl. 2). Even the smaller faults show notable lateral persistence. Some of their actual planes are traceable in mines for at least 2 miles. Faults of small displacement are characteristic of the district and of much of the surrounding region.

The several types of faults recognized in the district include (1) vertical faults mainly of horizontal displacement (along shears), (2) bedding-plane faults and associated reverse faults, (3) normal faults, and (4) systems of fault wedges.

On the basis of relative differences in magnitude of displacement the faults of the district are described as major faults or minor faults. The major faults are those fractures whose displacements are commonly 20 feet or greater. They are more readily related to the regional deformation, and, for the most part, are in the vicinity of the first-order folds of the district. Minor faults are those fractures whose displacements are less than 20 feet, and commonly only a few feet. Most of these minor faults are related to the second- and third-order folds.

MAJOR FAULTS

Reverse faults whose vertical displacements are in excess of 20 feet are found locally along the steeper north limbs of the two first-order anticlines traversing the district (pl. 8). These reverse faults are high-angle thrust faults that dip southward towards the anticlinal axes. Along the Meekers Grove anticline, similar first-order thrusts have been developed locally in at least three places—two near Meekers Grove—one of which is shown in figure 14—and the third at the locality known as Red Rock, southeast of Darlington, Wis., in the east-central part of the district. These faults are apparently discontinuous along the north limb of the Meekers Grove anticline as shown by unfaulted outcrops on strike between the known faults.

Along the thrust fault shown in figure 14 the middle beds of the Quimbys Mill member—that is, upper Platteville—on the south side of the fault are brought up approximately 20 to 30 feet against the Ion member of the Decorah formation on the north side of the fault. Although the actual plane is not visible, the classification of the fault can be inferred by a marked reverse-fault drag that is well exposed in the outcrops, and its dip can be inferred by a number of subsidiary, southward-dipping shears adjacent to the probable position of the principal fault plane.

A similar thrust fault has been noted along the north limb of the west half of the Mineral Point anticline. Field studies indicate that a southward-dipping thrust plane extends continuously from a point southwest of Livingston, Wis. (T. 5 N., R. 1 W.), along Crow Branch northwestward along the steeper north limb of the first-order anticline as far as it has been traced, which is a distance of at least 15 miles.

Plate 8 shows the location of this thrust fault and figure 21 shows a detailed section across the fault near its east end along parts of the east section lines of secs. 17 and 20, T. 5 N., R. 1 W. The measured displacement at this point is about 30 feet. The fault decreases in displacement towards the east, branches and dies out as three reverse faults with small displacements at the Crow Branch mine. Farther to the west a much greater displacement is suggested by a zone of intense fracturing and steep tilting of the beds. Probably this fault acted as a shear plane providing a major relief of compression all along the western half of the Mineral Point anticline.

Several other major faults, probably of reverse type, are known in the district. One of these is the Bee-

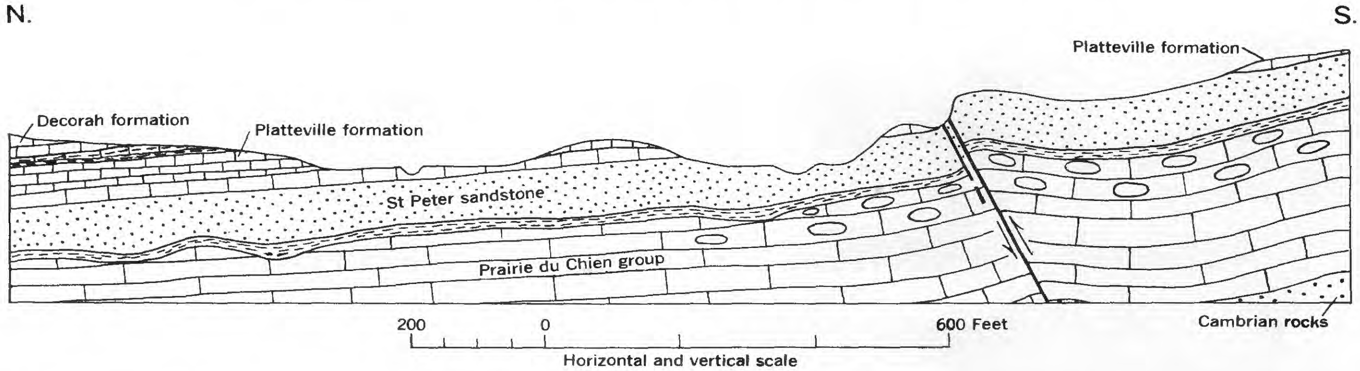


FIGURE 21.—Vertical section across the north limb of the Mineral Point anticline showing the first-order thrust fault as exposed in outcrops in the east halves of secs. 17 and 20, T. 5 N., R. 1 W. For general location see plate 8.

town fault (pl. 7), which extends in a N. 70° E. direction across the S½ sec. 29 and into the northwest corner sec. 28, T. 4 N., R. 4 W. This fault lies along the axis of a prominent syncline of similar trend. The fault trace is marked by a wide zone of fractured, brecciated, and altered rock as well as by a sudden rise of about 30 feet in the beds to the north. Highly recrystallized sandstone boulders similar to those found along other faults, and to those in sandstone dikes along faults, are added evidence of a major fracture here. The displacement along this fracture is not observable, but a thrust or normal fault appears more probable from the geologic relations than a shear fault.

Another major reverse fault is well exposed on the east bank of the Little Platte River in the N½SE¼ sec. 18, T. 3 N., R. 1 W. (pl. 8). This fault, named the "Capitola" fault for a zinc mine along it, has a N. 80° E. strike. The fault zone, 100 feet wide, consists of numerous inclined fractures having a general southerly dip of between 45° and 60°. Along the fault zone beds of the McGregor limestone member, which are normally limestone, have been dolomitized and fractured into a coarse breccia. The beds show a marked reverse-fault-type drag, and those to the south have moved up about 25 feet with respect to those to the north. The north edge of the fault zone is exposed on its trend at the Capitola mine west of the Little Platte River. The fault lies on the steep north limb of an eastward-trending anticline.

A fault of considerable displacement is exposed in a quarry on the northeast bank of Dodge Branch (fig. 22) in the NE¼ sec. 24, T. 5 N., R. 4 E., 1 mile northwest of Hollandale, Wis. The fault cuts the beds of the Prairie du Chien group, strikes N. 35° W., and dips 70° SW. The beds on both sides of the fault strike N. 35° W., dip 30° toward the northeast, and

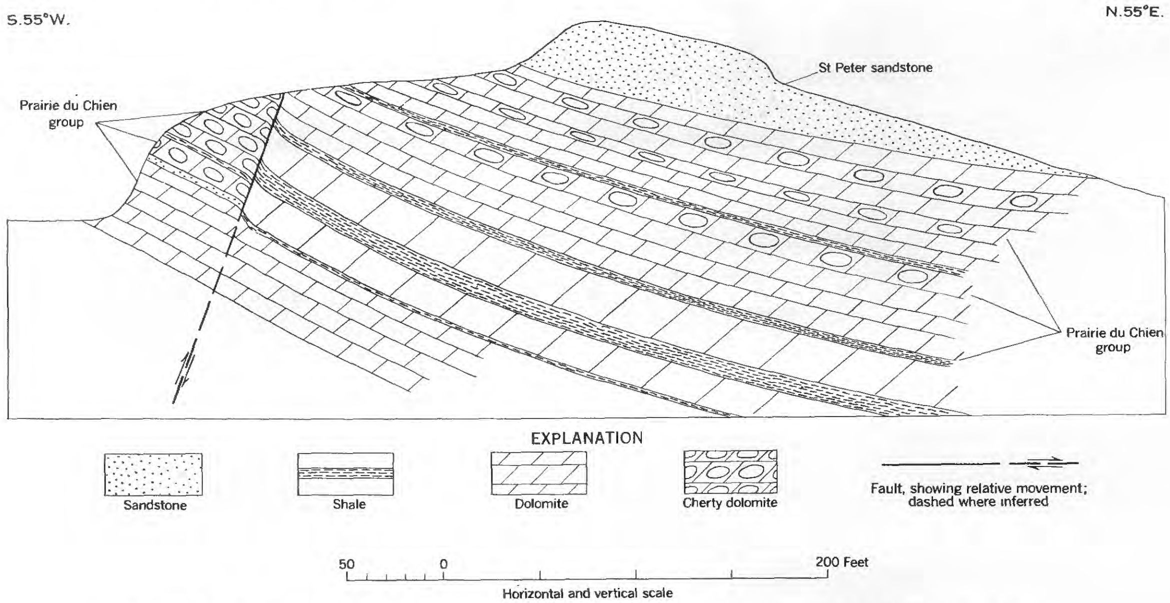


FIGURE 22.—Sketch illustrating a reverse fault exposed 1 mile northwest of Hollandale, Wis.

show a marked reverse drag on both sides along the fault. On the southwest side of the tight fault plane, sandy somewhat cherty dolomite beds of the Prairie du Chien are exposed to a height of about 30 feet, but on the northeast side are markedly different noncherty beds of the same formation. A minimum of 30 feet of vertical displacement is indicated by the fault relations exposed in the quarry. The rocks on the southwest side have been moved up relative to those on the northeast side. That the fault zone extends along the same general trend is strongly suggested by highly fractured exposures of these two formations toward the southeast, and an unusually large spring on the strike of the fault to the northwest.

Transverse shear faults of first-order magnitude have been noted at several localities within the district. The one showing the largest displacement is the Mifflin fault in secs. 22, 26, and 27, T. 5 N., R. 1 E., a mile northeast of Mifflin, Wis. (pls. 2 and 8). The plane of this fault is not exposed, but the evidence for its existence is found at the mouth of a small northwestward-draining tributary valley of the westernmost branch of the Pecatonica River. On the southwest bluff bordering this small valley the horizontal, basal Prosser cherty member of the Galena dolomite is exposed, whereas to the northeast and at the same altitude, horizontal beds of the upper McGregor member of the Platteville formation crop out. A rise of the beds to the northeast, 65 feet in 200 feet, is indicated across this valley. The rocks of the southwestern bluff are cut by a series of nearly vertical, northwestward-trending minor shear fractures which strike parallel to the probable strike of the fault. Several large, iron-stained sandstone boulders are imbedded in the soil of the valley floor. These boulders are St. Peter-type sandstone and are probably either from a block thrust up along the fault plane or from a sandstone dike in which the sandy material was forced up along the fault plane, similar to clastic sandstone dikes that have been found along faults elsewhere in the district.

The Mifflin fault was not traceable northwest from the Pecatonica river east of the Dolphin mine owing to the absence of outcrops or drill holes near the inferred extension of the fault. To the southeast of the Pecatonica river in sec. 26, T. 5 N., R. 1 E., the fault zone is traceable by: (1) A brecciated zone exposed in 1944 in the small brook east of the Okay mine and reported by miners to be present also in the northeast workings of that mine; (2) the ore body of the Old Slack mine is deposited in a northwest-striking shattered zone where an abrupt 15- to 20-foot rise in the beds to the northeast of the zone probably indicates the vertical component of displacement of the fault; (3) a line of drill holes intersecting the strike of the fault between the Old Slack mine and the Mifflin-Mineral Point road cut a 200-foot wide zone of pyritized breccia; (4) a line of old lead mines south of the road may mark the southeastern end of the mineralized fault zone.

Carlson (report in preparation) found a major fault that branches west from the Mifflin fault in the northeast corner of sec. 28, T. 5 N., R. 1 E., and extends into sec. 29 between Coker No. 1, and Coker No. 2 mines. The rocks to the north of this fault are displaced down relative to those to the south.

The Mifflin fault and related geology are shown on plate 2. The structural features suggest that the rocks on the southwest side of the fault had moved about 1,000 feet to the northwest, relative to the rocks on the northeast side, as indicated below.

1. The Okay mine ore body is offset about 1,000 feet northwest of the Slack ore body. Both ore bodies are controlled by distinctive fracture systems that consist of bedding-plane faults from which southward-dipping normal faults branch steeply upward. Fracture systems of this type are rare in the district. Both ore bodies have easterly trends and so closely correspond in nearly all other characteristics that quite probably they are the displaced parts of a once continuous fracture zone.

2. The main anticlinal axis to the northeast of the fault in the central part of the area (pl. 2) turns to the northwest apparently as a result of drag along the fault.

3. The main synclinal axis shown in the northwest corner of the area apparently has been displaced about 1,000 feet to the southeast on the northeast side of the fault.

Elsewhere in the district shear faults of smaller displacement than the Mifflin fault have been observed or have been postulated, but only in the Liberty mine (pl. 3), NE¼ sec. 16, T. 2 N., R. 1 E., has the actual plane of one of these faults been seen and the full displacement measured. A map and a section across this fracture are shown in figure 23. In the western end of the mine the vertical plane of the strike-slip fault is well exposed for a length of 350 feet and a height of 35 feet. Its walls are smooth, slightly wavy, and in places horizontally grooved and slickensided. Between the two walls is a gouge zone, from 4 to 18 inches thick, which contains rock fragments and locally a vein of unsheared sulfides. The net slip of 25 feet is indicated by the displacement of an earlier reverse fault cut by this shear fault. Veins of unsheared ore fill both of these fractures and indicate that both faults were developed before ore deposition, but the reverse fault is the main ore-localizing fracture of the ore body. That the shear fault movement is strictly horizontal is shown by horizontal slickensides and by the lack of any vertical dis-

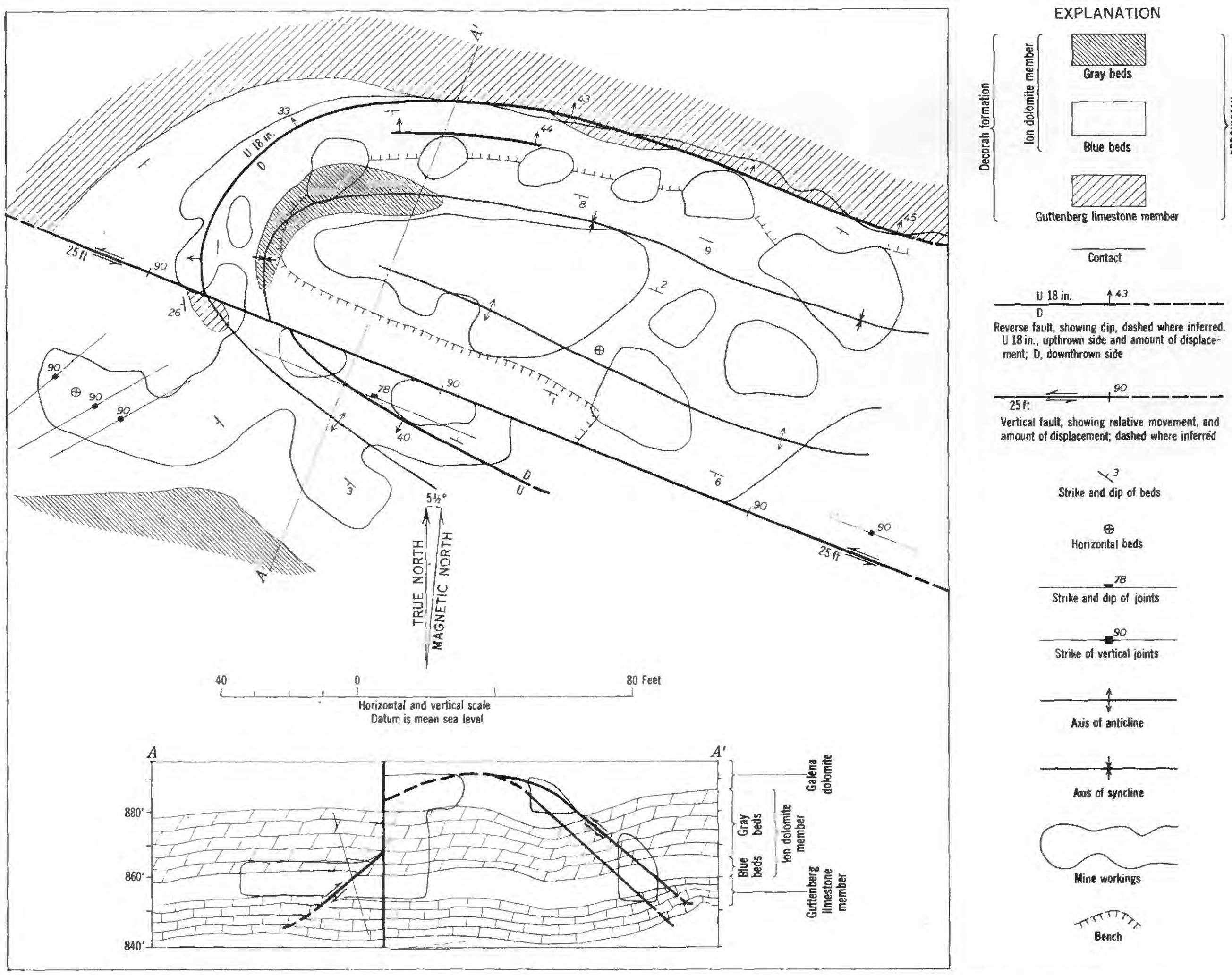


FIGURE 23.—Geologic mine map and section showing the shear fault in the west end of the Liberty mine. Note the displaced reverse faults that control the ore body. Location, NW¼NE¼, sec. 16, T. 2 N., R. 1 E.

placement of the beds (see section, fig. 23). The evidence above clearly indicates that in this mine the shear faults are later than the reverse and bedding-plane faults they displace.

A probable fault of the shear type is in the E½SE¼ sec. 16, T. 2 N., R 1 E. (pl. 3). Although this fault can no longer be seen because of the inaccessibility of the workings of Connecting Link mines, mining men provided descriptions of it and drill-hole data from which the type of fault and its displacement can be inferred. The displacement is essentially horizontal and amounts to 200 feet. These men [12] stated that a vertical, northward-striking, iron-sulfide-filled fracture, abruptly delimits the 60-foot wide ore body at the northwest mine face of the Connecting Link No. 2 mine. West of this fracture the rock was completely barren. In 1943–44 drilling southeast of Connecting Link No. 1 mine traced the ore body to a point 200 feet north of the northwest heading of Connecting Link No. 2 mine.[13] East of this point the rock was found to be completely unmineralized. This point at which mineralization abruptly ceased to the southeast of Connecting Link No. 1 mine is directly north and on the trend of the large fracture that delimited the northwest end of the Connecting Link No. 2 ore body. Thus both ore bodies end against this northward-trending line. The structures of the two ore bodies ending against this fracture are very similar, indicating that they are the same fracture zone displaced laterally about 200 feet. This north-striking vertical fault appears to be of the shear type, and has little vertical displacement. The presence of mineralization, in both the shear fault and the ore-body fracture system, sug-

[12] Including, among others, John Sellick, former mine foreman, and E. J. Deutman, mining engineer, and former operator of the Connecting Link No. 2 mine.

[13] Records provided by C. W. Stoops, geologist and former mine operator.

gests that this shear fault was developed, as in the Liberty mine, after the development of the ore-body fracture system and before mineralization.

Other faults possibly of this shear type, accompanied by a considerable vertical component of movement, are located in the NE¼NW¼ sec. 8, T. 1 N., R. 2 E. along Shullsburg Branch west of the town of Shullsburg, Wis. (pl. 5).

An example of a bedding-plane fault accompanied by subsidiary block faulting was exposed (until 1953 when it was covered by road fill) a mile east of Tennyson, Wis., along a small stream running northward into the Tennyson branch of the Platte River (NW¼SE¼NE¼ sec. 36, T. 3 N., R. 3 W. (pl. 6)). The bedding-plane fault lies within the soft, plastic shale of the Spechts Ferry (fig. 24). This incompetent shale acted as a lubricating layer within which the fault plane developed between the overlying and underlying more competent limestone beds. These shales flowed and were sheared, and the included limestone layers were broken into blocks that are now considerably separated. The overlying more competent beds of the Guttenberg are cut by a series of minor normal and reverse faults (pl. 6), that strike N. 70° W., between which the blocks of limestone have been rotated with the result that the beds dip steeply southward. The surface of the main bedding-plane fault is exposed for more than 125 feet along the creek, but other exposures indicate that the plane extends over a much larger area, possibly a mile west of, and several hundred feet north and south of the outcrop. The horizontal displacement is not measurable but is probably extensive, as indicated by the magnitude of the disturbance which is comparable to that of other major faults in the district. Minor northward-dipping reverse faults (two are shown in fig. 24, others are to the south), small asymmetric drag folds in the top of the Spechts Ferry strata, as well as the direction of rotation of the tilted blocks suggest that the rocks underlying the Spechts Ferry moved north relative to the overlying beds. The fault is probably an underthrust from the south acting through the competent underlying beds inasmuch as the overlying beds of the Guttenberg are relatively stretched and lengthened by rotational movement along numerous normal faults.

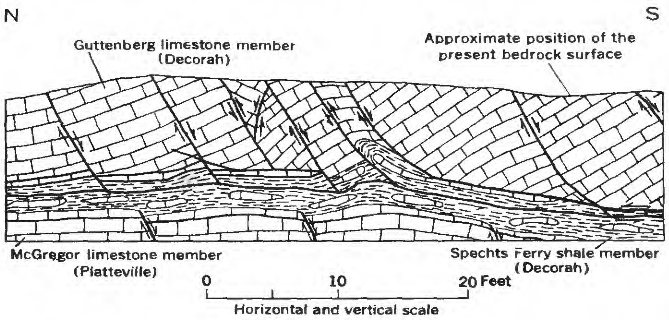


FIGURE 24.—Section illustrating exposed relations of the bedding-plane fault and the accompanying minor wedge faults exposed east of Tennyson, Wis. See S½NW¼ sec. 36, T. 3 N., R. 3 W. on plate 6 for the location of the fault.

About half a mile to the west in the main Tennyson Branch valley in the S½NW¼ sec. 36, T. 3 N., R. 3 W., approximately on the trend of the projection of this fault is a larger area of similar block faulting and rotated blocks on a scale that indicates the presence there of the same or a similar bedding plane fault in the Spechts Ferry shale member.

MINOR FAULTS

Minor faults are abundant throughout the district. Faults of this magnitude include small bedding-plane and reverse faults of less than 20 feet displacement together with their associated fractures. The minor faults are the principal structures controlling the zinc ore bodies in the lower part of the Galena, and in the Decorah, and in the upper part of the Platteville formations. These faults, where filled with vein minerals, are known as pitches (the reverse and rarely the normal faults) and flats (the bedding-plane faults). A typical steep pitch with minor footwall flats in shown in figure 25. Less abundant minor faults include small normal faults and wedge-fault systems.[14]

The reverse and bedding-plane faults are zones of fracturing along the limbs of the second- and third-order folds. These premineralization fractures and their associated breccias are the principal sites of deposition of the ore minerals. The two principal types of faults are interrelated in their development but are different because of the distinctive modes of relief of the well-stratified beds involved. Characteristically these faults, though of small vertical displacement, are traceable up to 2 miles along their strikes. They are situated not only along the limbs of the folds, but also commonly around the ends of the folds and form general arcuate patterns in the plan view. Most of these fault zones have been produced only along parts of the limbs of the folds, but a few form a complete belt about the fold and result in a horizontal elliptical pattern (fig. 27). More commonly the fault zones partly enclose synclines, but many examples are known in which they surround anticlines.

Many reverse faults transgress 50 to 200 feet of beds. They may occur as single fractures, but in many places

[14] The minor faults of all types found in the ore bodies have been further displaced and opened in places by solution sag. The writers are including in this discussion of faults (reverse, bedding plane, normal, and wedge faults), faults of tectonic and less commonly slump origins, but generally a combination of these origins. Reverse, bedding plane and normal faults are defined by their attitude and direction of displacement and not by the origin of the producing forces.

FIGURE 25.—Main pitch reverse fault along the west side of Graham Ginte mine. Vertical displacement along the fault plane is about 3 feet. Hanging-wall drag is apparent. Note veins of zinc ore (light bands in fault plane and in footwall) along fault and as flats along bedding planes in the footwall. Photograph by H. B. Willman, Illinois Geological Survey.

they comprise a zone of closely spaced parallel imbricate fractures. In such a zone (fig. 26), the hanging-wall fault has generally the greatest displacement; the movement along each thrust plane decreases in magnitude successively toward the footwall. The fault planes have an average dip of 45°, but many dip as low as 30° or as high as 60°. Most of the reverse fault planes flatten downward and join underlying bedding-plane faults in the soft plastic Spechts Ferry shale member at the base of the Decorah formation (fig. 26). In the overlying beds a similar series of bedding-plane faults form a general interconnected system. The reverse faults either die out gradually upward or stop abruptly at the junction with a bedding-plane fault.

The planes of the reverse faults nearly everywhere dip toward the anticlinal areas (fig. 30). The relation of these faults to folds is shown in figures 27, 28, 29. In the Coker mines (fig. 27), the fault zones are found only on the flanks of the folds. In Coker No. 2 mine the zone follows the flanks and swings around both noses of the canoe-shaped anticline to form a complete belt about the fold. In the Indian Mound mine (fig. 28), a similar arcuate fault zone forms a belt around the east end of a third-order syncline. In this mine, also, the reverse faults dip toward the surrounding anticlinal area. In the Kennedy mine (fig. 29) the main

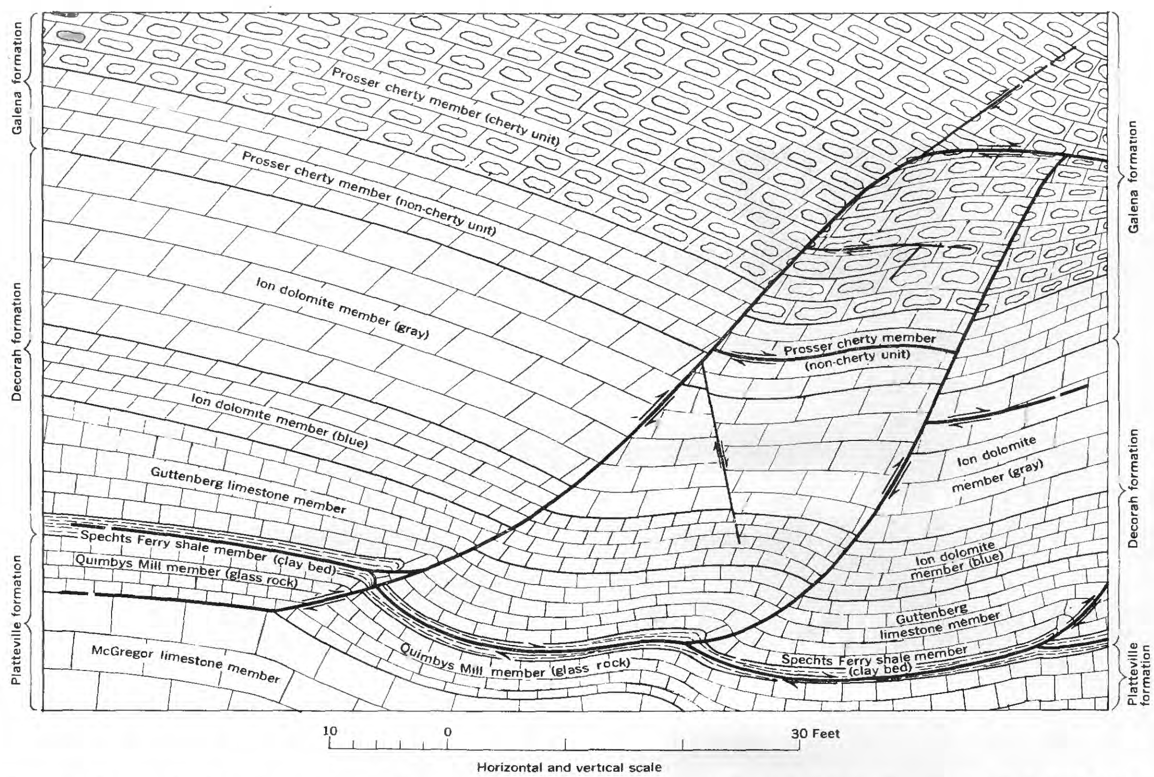


FIGURE 26.—Idealized section of the fault and drag-fold relations on a limb of a fold in the upper Mississippi Valley zinc-lead district. Commonly such fault zones contain zinc ore bodies.

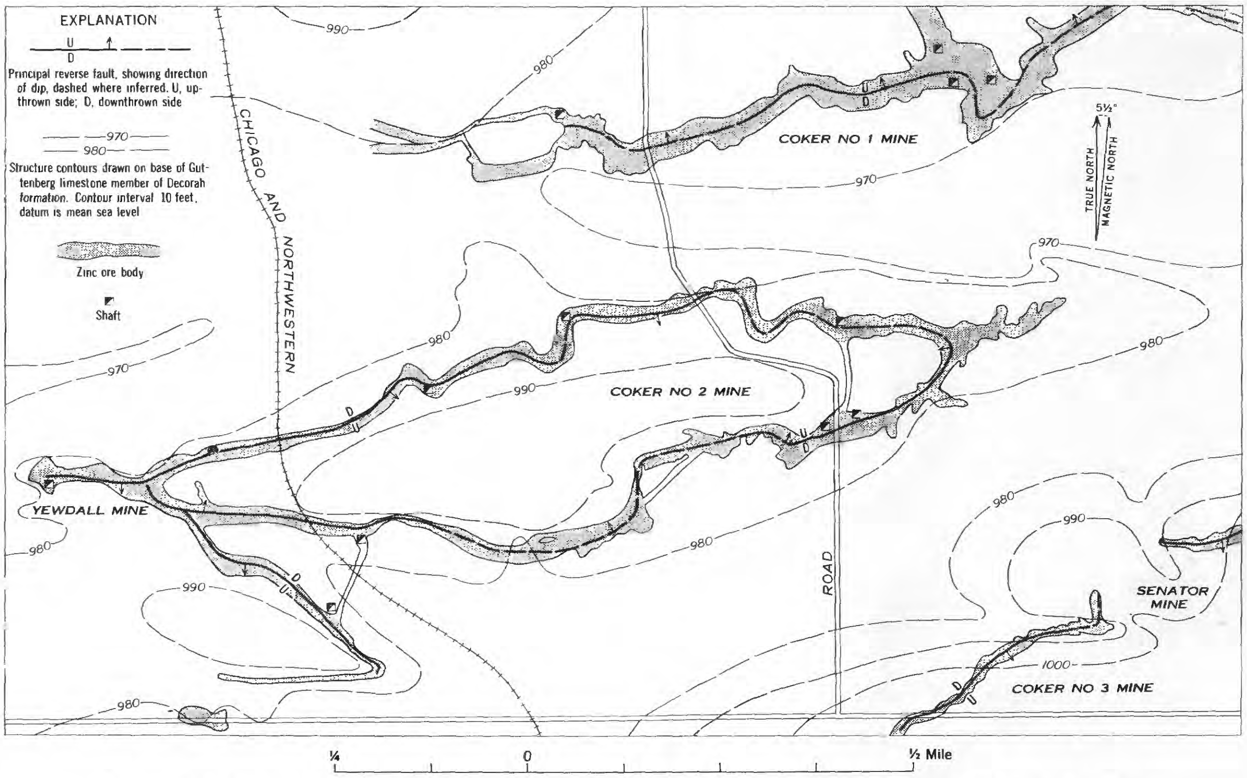
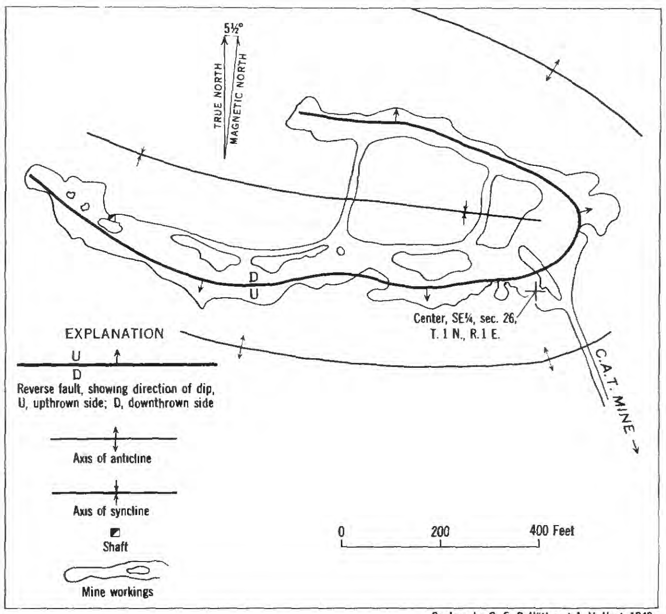


FIGURE 27.—Geologic structure map of the Coker mines, secs. 29, 30, T. 5 N., R. 1 E., 2 miles west of Mifflin, Wis.



Geology by O. E. DeWitt and A. V. Heyl, 1949

FIGURE 28.—Map of the Indian Mound mine at New Diggings, Wis., showing the principal controlling folds and faults.

reverse fault zones form parallel belts on the limbs of a northwestward-trending syncline and also along the sides of a local eastward-trending branch syncline. Likewise, they dip toward the bordering anticlinal area.

Figure 30 is a cross section through typical fault zones on the flanks of a syncline. The two sides of the structure show two stages of development for the minor fault zone. The faults of the south limb have reached an advanced stage of development for the minor fault zones in the district. The reverse faults are steeply inclined smooth-walled fractures that cross the bedding planes without sharp bends or projections. Four principal reverse faults have formed, and progressively toward the synclinal axis the individual faults have decreasing displacements and less regular planes. The north-limb fault zone exhibits a less advanced stage of development. A series of three weaker fractures of more steplike pattern are developed. The reverse-fault plane rises from the bedding-plane fault in the "toe" area to a more resistant bed above and then turns sharply toward the synclinal axis along a bedding plane to form a bedding-plane fault. This bedding-plane fault may continue for a few feet to a point where an inclined fracture again extends upward into the overlying beds to form a steplike pattern like that shown in the upper part of the north limb fault zone. Where the fault zones are even weaker, as near Dodgeville, Wis., only the bedding-plane fault near the base of the Decorah is commonly observed, and a few incipient reverse faults branch into the beds above.

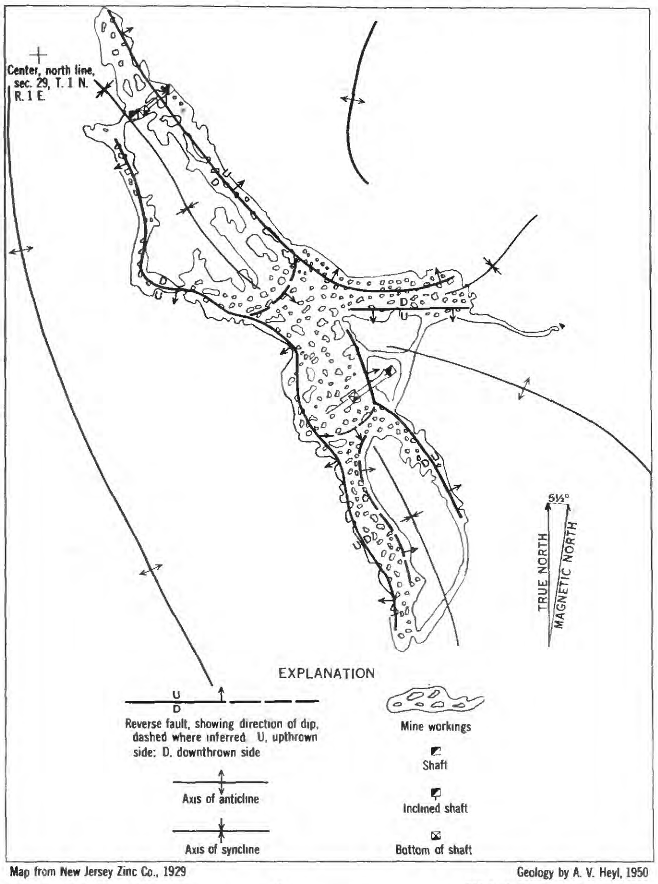


FIGURE 29.—Map of the Kennedy mine, 2 miles west of Hazel Green, Wis., showing the principal controlling folds and faults.

In the simplest form, where the faulting is essentially incipient, the bedding-plane fault alone is developed along a surface favorable to movement (generally along an incompetent layer), and the inclined fractures are absent (fig. 45, section 3). The bedding-plane faults can be recognized by slickensides along the bedding surfaces, by brecciation, by gouge, by local transections of the fault plane across a few beds, and in places by separation of the bedding planes.

Detailed features of a typical reverse and associated bedding-plane fault are shown in figure 31. The total displacement, including the marked drag of the beds, amounts to 10 feet, and a 6-foot vertical displacement is present along the fault plane itself. Noteworthy features are the smooth walls and gently curving plane characteristic of the reverse faults when fully developed. Another important feature is the flattening of the dip of the reverse-fault plane in the less competent lower beds near the "toe" of the fault, just before it joins the initial bedding-plane fault in the Spechts Ferry shale member. At the junctions of the reverse faults and the footwall bedding-plane faults, wedge-shaped openings along bedding planes in the footwall were formed by the drag of the hanging wall along the fault plane. Normally the fault planes are partly filled with gouge and breccia fragments. Where the faults are mineralized, they are filled with vein minerals that form symmetrically banded veins or replace the gouge. Sharp turns in the fault planes are generally marked by large openings, owing in part to differential displacement and in part to later solution. Some of these openings are filled with gouge, breccia, and ore, and contain crystal-lined vugs in the centers.

Small normal faults (fig. 26) are characteristic of the footwall area of the general fault zone in some places. These normal faults are inclined in the direction opposite to that of reverse faults and are generally open irregularly walled fractures of small displacement and limited extent.

In a few places within the district, wedge-fault systems have been observed as small parts of larger complex structures. Some of the localities in which this type of faulting was observed were (1) in the Graham-Ginte mine (figs. 42 and 43) 3 miles north of Galena, Ill., in the central axial area between the two opposing reverse fault zones; (2) at Red Rock, Wis., along the crest of the Meekers Grove anticline (fig. 32); and (3) in the area of complex structure just east of Tennyson, Wis.

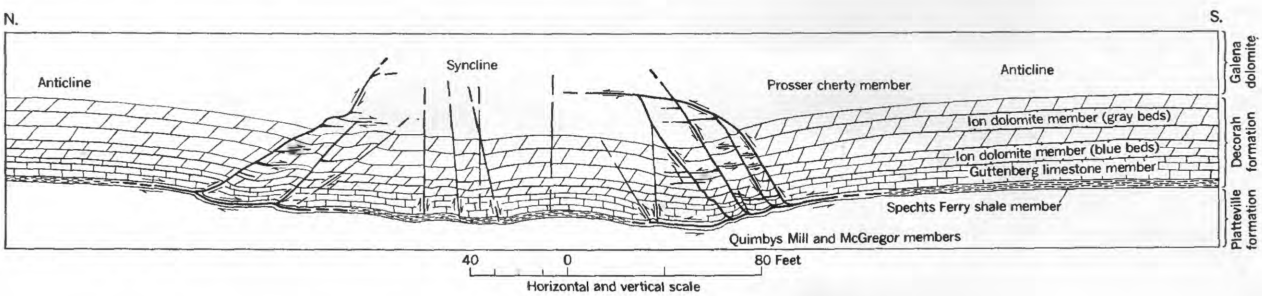


FIGURE 30.—Section across a third-order syncline showing the typical bordering fault zones of bedding-plane and reverse faults on the flanks of a syncline. Note the contrast between the more steplike weaker fault zone on the north limb of the syncline, as compared with the more numerous straighter reverse faults on the south limb. Drawn to scale from detailed mapping and sketches in the Trego mine, Platteville, Wis.

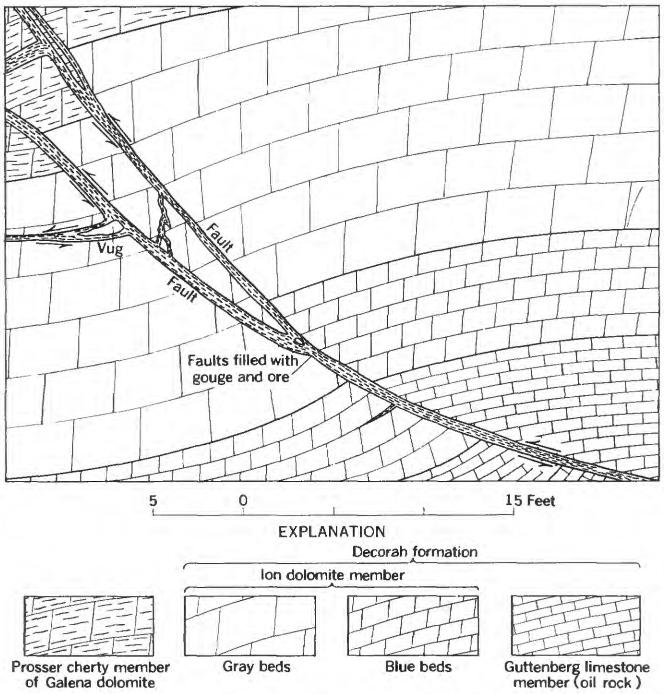


FIGURE 31.—Lower part of a typical reverse fault in the Martin mine, Benton, Wis. Note the narrow smooth-walled fault filled with gouge and sulfides to form a pitch, and branching bedding-plane faults in the footwall opened at the junctions with the reverse faults by tensional drag. Note, also, the drag of the beds along the fault and diminishing dip of the fault plane in the lower incompetent beds as the junction with the underlying main bedding-plane fault (not shown) is approached. Section drawn from the mine face.

JOINTS

In the preceding section the fractures that control the fault-zone type of zinc ore bodies are described. In this section the joint systems that control the formerly commercial gash-vein lead deposits of the upper Mississippi Valley district are discussed.

All the rock formations in the district contain well-developed vertical and inclined joints (pls. 6 and 7). The vertical joints commonly strike in remarkably straight lines (pl. 4). They fall into three groups (fig. 33) that, in order of decreasing abundance, approximately are: (1) west, (2) northeast, and (3) northwest. Lead ore has been deposited as gash veins of short vertical and lateral extent in many of these joints in the Galena dolomite. These gash-vein deposits were the first ore bodies to be mined in the district, and in the period between 1825 and 1860 they were the principal source of lead in the United States. Thousands of the joints are delineated by the old lead-mine workings, which afford an unusual opportunity to determine the trends, interrelations, and characteristics of the joints.

FIGURE 32.—Minor wedge faults in the St. Peter sandstone along the axis of the Meekers Grove anticline at Red Rock, Wis., sec. 17, T. 2 N., R. 4 E.

A typical pattern of joints in relation to the synclinal fold crossing part of the Potosi area, determined from field mapping, is shown in figure 33. The joints fall into three distinct groups, trending (1) W.–N. 65° W., nearly parallel to the fold; (2) N. 20°–30° E.; and (3) N. 20°–30° W. Therefore, the joints appear to be related to the fold as follows. The first group (W.–N. 65° W.) are mainly tension joints as indicated by the fact that these joints are rather open. The second group (N. 20°–30° E.) and the third group (N. 20°–30° W.) are a pair of shear joints that form an acute angle that is approximately bisected by the plane perpendicular to the axis of the fold (fig. 34).

This relationship appears to prevail throughout the district. In the following discussion the group of joints of W.–N. 65° W. strikes will be referred to as

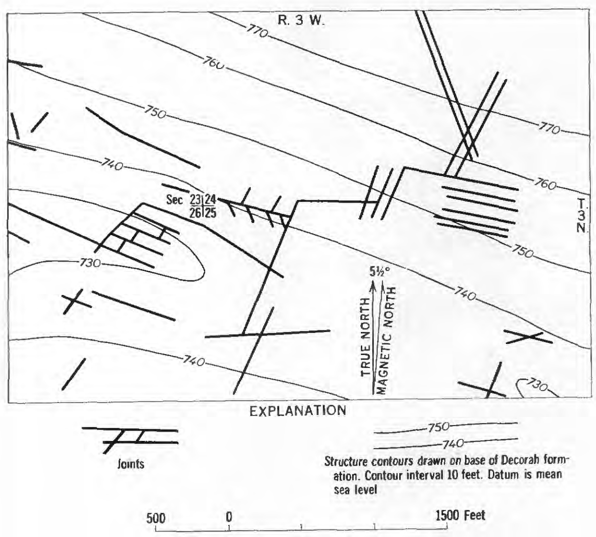


FIGURE 33.—Map showing folds and joints in parts of secs. 23, 24, 25, 26, T. 3 N., R. 3 W., northeast of Potosi, Wis. The trends of the known traced joints are illustrated. Note the relation of the strikes of the joints (shown as heavy straight lines) to the N. 70° W. trend of the syncline (shown by the structure contours). The joints fall into three groups, trending (1) W.—N. 65° W., (2) N. 20°–30° E., and (3) N. 20°–30° W. For further details see plate 6.

the J_1 joints; the northeastward-striking group of the pair of shear joints will be designated J_2 joints; and the northwestward-striking group of the pair of shear joints will be called J_3 joints.

The relationship of all the recorded joints in the entire Potosi area (pl. 6), western part of the district, in respect to the associated folds is shown in figure 34. The lower diagram shows the trends of all the folds in this area, and the general trend is approximately west although individual folds range in trend from N. 50° W. to S. 50° W. Very few fall within the range of N. 40° W. to N. 40° E. The upper diagram indicates the strikes of all the joints measured in the Potosi area. Here, as in the previously described local area, the joints fall into three groups—J_1 (W.–N. 60° W.), J_2 (N. 20°–40° E.), and J_3 (N. 20°–30° W.). The most common direction is N. 70° W. (J_{1a}), which forms the prominent apex in the diagram of the J_1 group; a second and less prominent apex is along the approximately west trend (J_1). As in the local part of the Potosi area previously described, the J_1J_{1a} joints are generally parallel to the general trend of the fold axes whereas the J_2 and J_3 joints form a shear pair. Open fissures and down-dropped rock wedges are characteristic features of J_1 joints, but some of the J_1 joints are smooth-walled fractures with evidence of shear movements such as local horizontal slickensides and fracture cleavage along their walls. Although they are mainly tensional fractures, they are apparently compressed and sheared locally before their final development as tension fractures. The J_2 and J_3 shear-joint pair consist of relatively tight fractures that are only locally mineralized.

In the larger Hazel Green-Shullsburg area (pl. 5), south-central part of the district, a similar and even clearer relationship exists. Figure 35 diagrammatically shows the trend of the joints in this area. Here also the joints fall into three distinct groups: west (J_1), northeast (J_2), and northwest (J_3). The J_1 joints are relatively open, and many of them contain galena veins. The J_3 joints are open only in a few places and contain narrow galena veins. The J_2 joints are commonly tight fractures. Figure 19 diagrammatically illustrates the trends of the third-order folds in this area and the general strikes of the joints in relation to them. The J_1 joints strike parallel to the most abundant westward-trending folds and the J_2 and J_3 joints form a shear

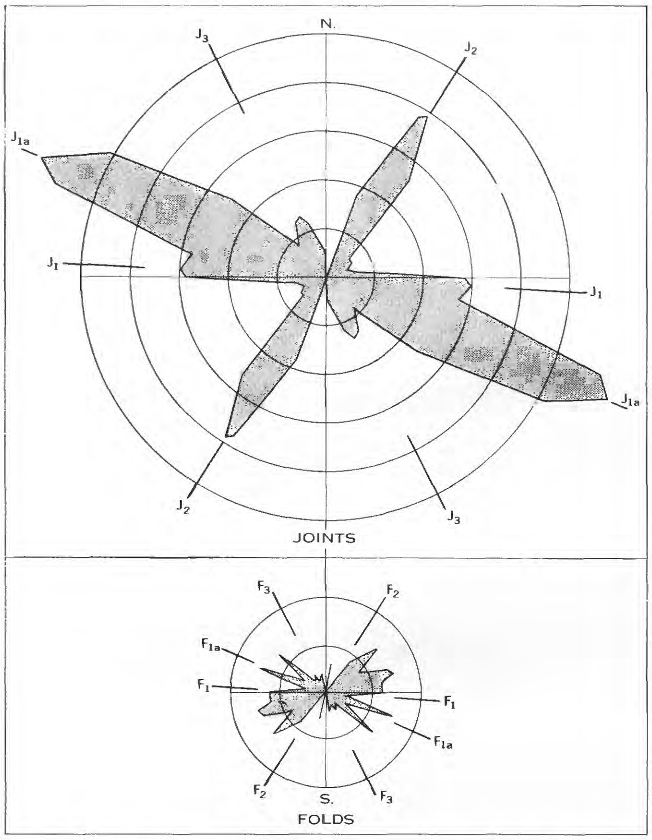


FIGURE 34.—Diagrams illustrating the relations of the joint and fold trends in the Potosi, Wis., area. In the upper diagram each circle indicates 10 joints, in the lower diagram 5 folds. In the upper diagram, there is a compilation of 309 joints, in the lower diagram 60 folds. Dashed radiating lines show where the major joints trends fall in relation to the folds.

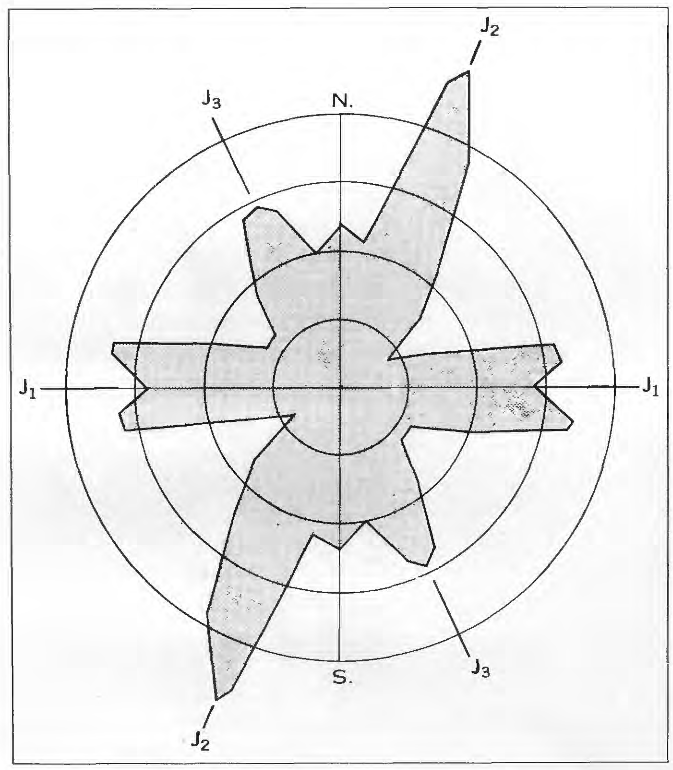


FIGURE 35.—Diagram showing the trends of the vertical joints in the Hazel Green-Shullsburg area. Note the three major joint groups; J, tension joints, and J_2 and J_3 shear joints. This is a compilation of 212 joints. Each circle indicates 5 joints.

pair whose acute angle is bisected by the northward-trending plane normal to the most prevalent westward-trending fold axes. The northwest-trending crossfolds are nearly parallel to the J_3 joints, and some of these folds may have been formed along zones of weakness developed by master J_3 joints.

This general relationship of the joints to the folds appears to be characteristic of the district as a whole and serves to illustrate the similar patterns noted elsewhere in the individual areas studied.

In many places throughout the district the joints are filled with veins of galena, and the veins along joints approaching the northward direction (J_2 and J_3 joints) are known in the miners' terminology as "north and souths". These joints are relatively tight, and therefore the galena is usually found in vertical veins, from half an inch to 3 inches in thickness, as a solid band between the walls. In this respect they differ from the veins typical of the more open J_1, "east and wests". The west-striking joints tend to be more continuously mineralized for ore was found along them in places for a distance of a mile, and in one locality at least, at intervals over a length of 5 miles. The ore is a single narrow vertical band where the walls are close together, but more commonly a band lines each wall of the more open fractures and together they enclose a central crystal-lined vug. Most of the lead ore was deposited in these "openings", which consist of podlike mineralized bodies oriented horizontally along the joints where the fractures cross a favorable zone of beds. The "openings" are nearly confined to the Galena dolomite and apparently were developed by the greater brittleness and more soluble character of these dolomite beds. The deforming action that broke the strata to form the J_1 tension joints tended to develop crackle breccia in the joint walls in these favorable beds. The ore solutions dissolved the more calcareous parts of the brecciated rocks to produce a porous mass and to enlarge the joint fissure in these beds to a podlike cavity (fig. 36). The lead ore was subsequently deposited along the cavity walls and within the interstices of the crackle-solution breccia. In many places these J_1 tension joints split and continue around downthrown central key rocks or horses.

Many of the joints have been widened above the water table by superficial weathering. As most of the lead mining was restricted to the rock above the water table, most of the older reports are confined to the descriptions of these weathered joints and associated ore deposits with necessarily little information about their unaltered appearance below the level of ground water.

In many places mineralized pods are found at the favorable zone of beds along the strike of the joint. In

FIGURE 36.—Vertical J_1 tension joint with partly mined lead-bearing "opening" exposed in Galena dolomite quarry at Rockville, Wis. "Opening" is partly filled with old mine waste. Beneath the mine floor considerable galena remains scattered throughout the vuggy brecciated rock of the "opening."

addition, several favorable zones, lying directly one above the other along the joint, form several superimposed parallel "openings". The intervening areas between the podlike "openings", both vertically and laterally along the joints, are marked by single narrow joint fractures locally filled with vertical galena veins.

The mineralization along the joints was generally restricted to certain local areas. Commonly these mineralized joints consist of a series of parallel J_1 joints and the less commercially important J_2 and J_3 cross joints. The mineralized areas tend to trend northeast, and the ore-bearing J_1 joints are thus arranged en echelon in northeast-trending zones. In some localities, such as in the vicinity of Elizabeth and in Vinegar Hill Township, Ill., and just to the north, at Hazel Green, Wis., these northeast-trending zones of mineralized joints are directly within and along northeast-trending second-order synclines. A further tendency towards regular arrangement is the presence of master joints at fairly evenly spaced intervals, generally between several hundred and thousand feet apart; the intervening minor joints are distinctly of more local extent and, where mineralized, contain smaller ore deposits. In many other places the mineralized joints exhibit no apparent concentration in relation to the immediate local folds.

The district contains many inclined joints in addition to the vertical joints. Most of the inclined joints are tight fractures that zigzag across the bedding and occur in closely spaced zones although isolated fractures of this type are not uncommon. These inclined fractures are generally localized along, and strike parallel to, the limbs of individual folds. They have dips ranging from 40° to 60°, and although an individual zone may have all its fractures dipping in the same direction, two sets in some outcrops will have similar strikes but dip in opposite directions. The set that dip away from the syncline are tight, but the set that dip toward the syncline are more open and irregular. The tight set show evidence of shearing, and the more open set evidence of tension.

SANDSTONE DIKES

Thin sandstone dikes are fairly common in the district. They fill faults, joints, and fractures in the Platteville, Decorah, and Galena formations. They are more abundant in areas of more intense tectonic deformation, but are known elsewhere in the district.

Some well-exposed dikes are listed below, but many others are known to exist, and in other places their presence is indicated by large sandstone boulders found in areas of limestone and dolomite far up-drainage, or above the St. Peter sandstone outcrop areas.

Partial list of sandstone dikes and boulders

Location	*Illustrations (plate no.)*
Dike near Beetown, Wis., along Grant River, center N½SE¼SW¼ sec. 28, T. 4 N., R. 4W	7
Dike near Beetown, Wis., along Beetown fault, center, south edge, NW¼SE¼ sec. 29 T. 4 N., R. 4 W	7
Dike near Tennyson, Wis., along a branch of the Platte River, southeast corner, SE¼SE¼ sec. 24, T. 3 N., R. 2 W	6
Dike at Capitola mine, along Little Platte River, center, NW¼SE¼, sec. 18, T. 3 N., R. 1 W	1, 8
Boulders from probable dike along Capitola fault; ravine, south side Rountree Branch, center, T. 3 N., R. 1 W	------
Boulders from probable dike along Mifflin fault, SW¼ SE¼ sec. 22, T. 5 N., R. 1 E	2
Dike along from road, south of Victoria mine, center south part, SE¼SE¼ sec. 22, T. 5 N., R. 2E	1
Dike east of Meekers Grove in center of south part SW¼ NW¼ sec. 24, T. 2 N., R. 1 E	3
Boulders on north slope of Shullsburg Branch, 2 places near center SE¼ sec. 5, T. 1 N., R. 2 E	5
Dike in Wisconsin highway 11 roadcut, 1 mile west of Fairplay, Grant County, Wis	------

The dikes and boulders at all of the occurrences listed except near Fairplay are almost quartzite consisting of rounded frosted grains of St. Peter-type sand notably silicified with quartz crystal overgrowths and also some silica cement. In places some of the groundmass is pulverized dolomite and limestone and the dike may include a few angular dolomite rock or chert fragments. At Fairplay the dike is a fine-grained varved shaly dolomite deposited in flat, thin beds normal to the vertical dike wall.

The dikes, except the Fairplay dike, apparently were formed by strong tectonic pressures, aided by a hydrostatic head of ground water, injecting St. Peter sand and fragments from the limestone wallrocks upward through faults, strong master joints, and open fractures, into the overlying carbonate rock strata. After injection under pressure, solutions silicified and locally pyritized the dikes. The Fairplay dike is a cave- or joint-filling from above representing deposition of Dubuque or Maquoketa-like sediments by downward percolating waters. Later the sediments were lithified by dolomitization.

Some sandstone boulders have no known relations to sandstone dikes or fissures and though of notably similar lithology could be of a different origin.

ACCENTUATION OF STRUCTURE BY SOLUTION THINNING

The limestones of the district, and to a lesser extent the dolomites, have been altered by the mineralizing solutions. The three principal types of alteration are (1) silicification, (2) dolomitization, and (3) the dissolving of the calcareous rocks in the local areas through which the ore-bearing solutions passed. The third type of alteration is important in relation to the structure, inasmuch as the removal of the calcareous materials in mineralized areas has thinned some beds. This thinning, in turn, resulted in the local accentuation by minor slumpage of the earlier deformational structures through which the ore-bearing solutions passed. In contrast, the first two types—silicification and dolomitization—were relatively early and for the most part preceded the solution thinning. Where the beds were replaced by dolomite and silica, their relatively less soluble character prevented the later thinning of the strata by solution, and the beds in these places retain their original thickness. The fractures and folds in (and also above) the beds thinned by solution are very similar to those of fracture zones where no thinning occurred. The only apparent change is in the lithologic character and thickness of the beds in areas altered by solution action accompanied by a local relaxation by minor slump of the fractures in synclinal areas which border reverse and bedding-plane fault zones. In areas of extreme solution, some fractures, cave openings, and tumbled breccias are the result of slump and collapse.

Removal of calcareous rock is the most extensive type of alteration caused by the mineralizing solutions. This process has had its greatest effect on the limestones of the lower Decorah formation and the adjacent upper part of the Platteville formation. The dolomite beds of the upper Decorah and the Galena have been affected only locally and to a restricted extent.

The chief effect of solution was to dissolve, partly or completely, a calcareous layer, leaving only the argillaceous material of the bed as a residuum in the vicinity of mineralized areas. This results in all degrees of end product from nearly unaltered limestone to a carbonate-free shaly mass, difficult to distinguish from a primary shale. The removal of the calcareous beds results in this "shalification" and also, as might be expected, a thinning of the carbonate beds affected.

For example, the Guttenberg member of the Decorah formation is greatly altered in some areas. Normally it is a pinkish-buff to gray sublithographic limestone with minor interbedded carbonaceous shale partings and has an average thickness in the district of about 12 to 14 feet. Where greatly altered, it becomes a chocolate-brown carbonaceous residual shale mass ranging from 6 to 10 feet in thickness. Figure 37 shows an exposure of the Guttenberg limestone member in the Liberty mine, Meekers Grove, Wis. The light areas of strongly banded limestone and shale exhibit the typical lithologic character of unaltered Guttenberg. At the top and bottom along the right edge of the photo the limestone areas are less prominent and the banding broader and less regular owing to partial solution of the limestone layers. In the central part and the left side of the photograph are shown three downward-pointing wedge-shaped dark areas of shale produced by complete solution of the limestone. The right side of each wedge is bounded by an inclined presolution minor fracture. A similar fracture may exist on the left side also. The dissolving solutions, which apparently used the fractures as channels, have selectively attacked the wedge blocks and dissolved the limestones, leaving only a shaly residue. Close inspection of the faintly visible banding in the dark shale areas shows that the shaly residues have assumed a synclinal form; this depression has resulted from sagging of the thinned beds. Wherever found, the shalification that resulted from the solution action is closely associated with preexisting fractures. It is most prevalent in the rocks bordering the fractures and in associated shattered areas, where the solutions gained easy access. Commonly the shalification is prominent in areas that exhibit strong plastic flowage features (fig. 38); this relationship suggests that some of the solution took place under the compressive pressures of the last stages of the deformation. The softening of the rocks by the solution action aided in the deformation of these shaly residues by plastic flowage rather than fracturing.

FIGURE 37.—Solution synclines of altered carbonaceous shaly residues of the Guttenburg. The synclines are bounded by inclined presolution fractures on the right. Note intervening unaltered, and slightly altered, Guttenburg limestone member with thin interbedded shale partings that constitute the major part of the solution residue phase. East end of Liberty mine, Meekers Grove, Wis.

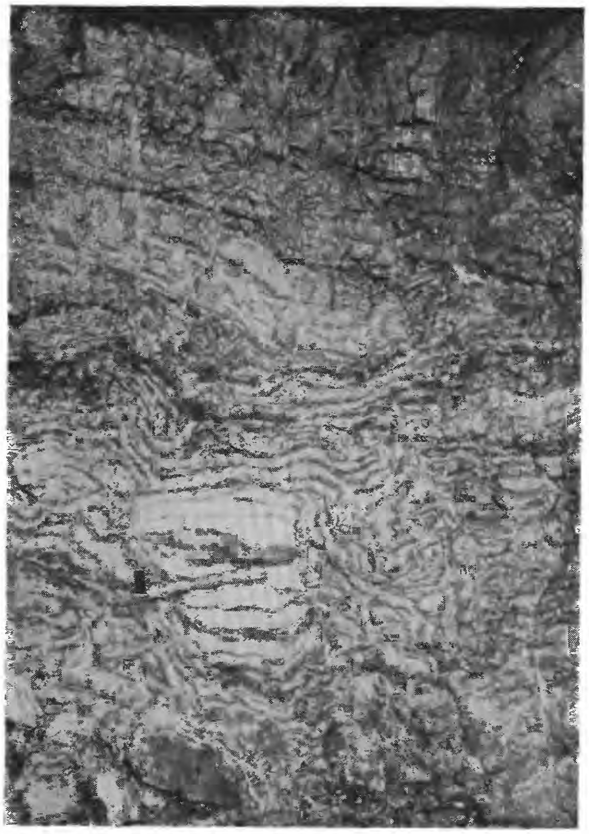


FIGURE 38.—Highly deformed solution-residue shales of the Guttenberg limestone. Note the unaltered limestone block in the central area bordered by contorted shales deformed by lateral compressive forces. Note lack of openings in the shale or in the overlying competent beds which are locally underthrust. In a 25-foot face, of which this view is a part, 13 feet of lateral shortening was measured. Central part of the Graham-Ginte mine. Photograph by H. B. Willman, Illinois Geological Survey.

The dolomitic strata of the upper Decorah and the Galena formations also were slightly altered by the solution thinning. The more calcareous parts of the beds tended to be dissolved but the magnesia-rich parts were more resistant. In these more resistant parts the solutions generally partly dissolved the carbonates. Minor thinning and irregular solution cavities and channels were selectively developed in the more calcareous parts of the rocks bordering fractures. The result is a porous, honeycombed rock. Pre-solution crackle breccias along the faults aided this process by providing solution access. These honeycombed rock areas are common in the dolomitic parts of the fault zones and along vertical joints in favorable strata. Very uncommonly ore-lined solution caves have been found (Chamberlin, 1882, p. 466–467).

In the lower Decorah and upper Platteville formations the thinning that resulted from the solution action, in some places reach 15 or 20 feet—about 33 percent of the original thickness of 55 or 60 feet—but most commonly it is less. Along the associated fault zones this thinning and a slight slumping tend to accentuate the fault-drag synclinal areas. Also, the slumping locally opened overlying fractures and produced minor breaks. The principal deformational fracture patterns were, however, essentially unchanged by the local slumping.

Solution structures in these formations are notably more abundant in certain parts of the district, such as near Shullsburg, Montfort, Livingston, Beetown, Wis., and Galena, Ill. In these areas, structures formed purely by solution accompanied by slump and collapse are common within parts of mineralized bodies. In addition, there are slump structures formed by solution and collapse along originally tectonic pitch zones, brecciated "core" areas, or along solution "openings" that follow tectonic joints beneath an undissolved cap rock, similar to the "openings" in the Galena dolomite. Such "openings" may be simple sag synclines, or which when further developed may have lenticular bedding plane cavities beneath the cap rock. In a further stage irregular open fracture and tumbled breccias are developed in the central part of the collapsed zones. Such solution developed structures are easily distinguished from tectonic structures by their open irregular fracture systems, by open tumbled breccias, and by the areas of greatest thinning and open fracturing in the central part of the dissolved zones with resultant sag of the strata in all directions towards this most dissolved area, which commonly had a centrally located joint or fault.

Relations between tectonic deformation and solution thinning are shown in figure 39. The beds are coarsely brecciated and partly dissolved limestone of the Guttenberg member, except for the roof of the stope (shown at the top of the picture) which consists of unbrecciated beds of the Ion. Examination of the mine face shows that the large partly dissolved block of rock upon which the base of the hammer handle rests is the downward displaced fragment of the nearly horizontal beds towards which the sharp end of the hammer points in the left center of the picture. The point of the hammer rests on an elongated mass of steeply dipping Guttenberg that has been completely altered to a soft brown clay. This thinned elongate mass is bent downward from the connected undissolved limestone beds in the upper right part of the picture and extends downward for about 2 feet beyond the two displaced limestone blocks previously described. (For similar examples, see Behre, Scott and Banfield, 1937, p. 779, figs. 9 and 10; and Behre, 1937, p. 526, fig. 11.) It is almost, but not quite, severed in the narrow space between the two displaced blocks. The elongate mass

FIGURE 39.—Coarse block breccia of shalified Guttenberg limestone member (so-called oil rock). Unaltered beds of the Guttenberg are visible for comparison at the right side of the photograph. The breccia is tightly healed by residue shales that have flowed between the large breccia blocks. Marked lateral shortening is indicated by the placement of the breccia blocks. Graham-Ginte mine north of Galena, Ill. Photograph courtesy of H. B. Willman, Illinois State Geological Survey.

has been bent and thrust down through the underlying beds and the rocks have been shortened laterally by this faulting by about 6 feet. In order to wedge its way through the underlying beds without crushing or flowing, the elongate mass must have had considerably greater strength at the time of thrusting than it has at present. This relationship suggests that the faulting took place before most of the solution thinning. However, the complete filling of the spaces around the larger fragments by smaller altered fragments and gouge and clay residues suggests that, after the initial faulting, the opened fractures allowed access of the solutions. They entered the brecciated area, and in the latter stages of lateral compression dissolved the limestone fragments. Plastic flowage of the clay residues under lateral pressure filled all available apertures between the larger blocks, which also were partly dissolved. After compression ceased some solution thinning of the brecciated areas continued and caused gentle slumping of the healed breccia mass parting it from the overlying beds of the Ion. This horizontal opening along the contact of the two beds was filled with sulfides and calcite (visible as the white patches at the upper left edge of the photograph).

ORIGIN AND MODE OF FORMATION OF THE STRUCTURE

SUMMARY OF PREVIOUSLY HELD IDEAS

The upper Mississippi Valley zinc-lead district has been studied by many of the distinguished geologists of the United States. The principal reports on the structure of the upper Mississippi Valley district are listed below in the form of an annotated bibliography. Unfortunately, it is not possible within the scope of this report to describe fully the large amount of information contributed by the earlier investigators. To show the progressive development of the structural knowledge of the area, the reports are listed in the order in which they were published.

1840, Owen, D. D., Report of the geological explorations of parts of Iowa, Wisconsin, and Illinois: Ex. Doc. no. 239, 26th Congress, 1st session, p. 19–22, 36–40.

This remarkable, early paper discusses structural features of several localities. Notes the regional strike as N. 70°–80° W. and the dip to the south between 9 and 17 feet per mile. Postulates the structures of the district as a slight basin with a center at Platte Mounds and local flexures in the south part of the district. Restricts the lead veins to the Galena dolomite and correctly divides the lead-bearing "fissures" into three groups, a principal group trending west or slightly north of west and minor groups trending northeast and northwest.

1854, Daniels, Edward, First annual report on the state of Wisconsin: Wisconsin Geological Survey, p. 20–29.

This early report divides the lead-bearing joints into their proper three groups. Notes also the presence of certain curved or "crescentic ranges", the first observation of the zinc-type ore bodies. Divides the veins into two groups, "perpendicular veins" and "flat sheets", placing the first group in the Galena dolomite and the second group in the underlying beds (Decorah).

1855, Percival, J. G., Annual report: Wisconsin Geological Survey, 101 p.; 1856, *idem,* 111 pp.

Contains detailed descriptions and map of the lead "crevices". First described the possibility of faulting. Recognized and located parts of the major folds of the district and recognized that folds had an important control on the ore deposits. First mention of pitches and flats.

1862, Whitney, J. D., Report on the lead region, Geology of Wisconsin: Wisconsin Geological Survey, v. 1, p. 73–420.

Claims there are no faults in the district. Suggests the existence of an eastward-trending uplift of the beds in the northern part of the district along Military Ridge. Describes the mineralized joints in great detail with illustrations and maps. Also describes pitches and flats, with examples.

1872, *Murrish, John,* Report on the geological survey of the lead regions, Wisconsin: Wisconsin State Agr. Soc. Trans. 10, p. 393–477.

Proposes that a northward-trending "axis of physical disturbance" passes through the district near and parallel to the fourth principal meridian, and that this axis is crossed by several eastward-trending belts of "upheaval". Concludes that the tectonic forces and "thermal agencies" that produced these disturbances are the source of the ore. Attempts to delimit the mineralized district into four eastward-trending belts identical with his proposed belts of "upheaval".

1877, *Strong, Moses*, Geology and topography of the lead region: Geology of Wisconsin, v. 2, pt. 4, p. 645–752.

Describes the structures of the district mainly by excellent data on the structures of the ore deposits.

1882, *Chamberlin, T. C.*, Geology of Wisconsin: Wisconsin Geological Survey, v. 4, p. 365–571.

Probably the most comprehensive study made of the entire district in the 19th century. Contains detailed discussions of the structure of the district with plates and maps. Notes the regional dip as southwestward. Emphasizes the importance of the Wisconsin arch, plus the fact that the strata contain lesser "undulations due to disturbance." Notes that the Paleozoic strata "suffered some very mild flexures" of an easterly trend, including arches at Red Rock, Meekers Grove, and near Mineral Point, Wis. Attributes these folds to "in part original deposition and, in part only, subsequent flexure", owing to lateral pressure, presumably owing to the cooling and consequent contraction of the earth. Notes no regular system of folds throughout the district.

States that most of the ore bodies lie within local basins. Carefully distinguishes between the ore bodies in the joints and "those which belong to the peculiar system of flats and pitches, or of simple flats", and asserts that all these bodies are part of "one complex system".

A brief summary of Chamberlin's hypothesis for the formation of the structures is given below. The "original undulations" resulting from deposition recognized in beds of the Platteville, Decorah, and Galena were compressed by a horizontal force from the south which deformed them slightly.

> "Where they were naturally arched upward (owing to the depositional high) they would under the action of the lateral thrust, arch still more highly, and would be most fractured upon the swell of the arch. Where they were bent downward, as in the case of the ore-bearing basins, the horizontal force would tend to bend them more deeply, and these would likewise be most fractured along the bed of the depression. When a movement took place in the opposite direction, the strata would settle back toward their original position. The result would be a closure of the fractures upon the outward curve of the arches and an opening of the fissures in the depressions. It is a well-known principle that, in the bending of a body, the cracks tend to diverge towards the convex side because that part is most stretched. So we find toward the bottom of the Galena limestone the crevices diverging in the peculiar form known as flats and pitches."

According to Chamberlin the deformation also affected the Paleozoic formations underlying the Galena, Decorah, and Platteville.

1893, *Jenney, W. P.*, The lead and zinc deposits in the Mississippi Valley: A. I. M. E. Trans., v. 22, p. 171–225.

Describes faults of considerable displacement at Dubuque and Lansing, Iowa. Postulates that these fractures are fault planes not restricted to one formation but extending through all formations above the Precambrian basement. The "fissures", he concluded, "are the result of forces connected with widespread dynamic disturbances". Considers the fractures and ore deposits to be a result of tectonic forces related to those that produced widespread disturbances, igneous intrusions, and mineral deposits in post-Cretaceous and Tertiary time throughout the Rocky Mountain system.

1893a, *Blake, W. P.*, Wisconsin lead and zinc deposits: Bull. Geol. Soc. America, v. 5, p. 25–32.

1893b, *Blake, W. P.*, The mineral deposits of southwestern Wisconsin: A. I. M. E. Trans., v. 22, p. 558–568.

Notes the importance of the "general regional parallelism of the ore-bearing joints with the structure of the region." Notes brecciation in the ore deposits and attributes it to solution and slumping. Like Jenney, he recognizes the presence of faulting in the district and stresses its importance in localizing the ore.

1895, *Calvin, Samuel*, Geology of Allamakee County: Iowa Geol. Survey, v. 4, p. 86–88.

Notes the presence of a broad northwest-trending anticline crossing Allamakee County, bordered on the northeast by a sharp parallel syncline. The anticline has an amplitude of 150 feet and is sharply asymmetric towards the northeast.

1897, *Leonard, A. G.*, Lead and zinc deposits of Iowa: Iowa Geol. Survey v. 6, p. 9–66.

Contains good descriptions of joint-controlled lead and zinc deposits in Iowa.

1900, *Calvin, Samuel, and Bain, H. F.*, Geology of Dubuque County: Iowa Geol. Survey, v. 10, p. 379–622, especially 478–597.

Describes gentle deformational folds at Spechts Ferry and at Eagle Point, Iowa. Recognizes that the deformation produced the widespread joints and local shear zones. Considers that Jenney's supposed faults are nonexistent.

1903, *Grant, U. S.*, Preliminary report on the lead and zinc deposits of southwestern Wisconsin: Wisconsin Geol. and Nat. History Survey, Bull. 9, p. 1–103.

1904, *Grant, U. S.*, Lead and zinc deposits of southwestern Wisconsin: U. S. Geol. Survey Bull. 260, p. 309–310.

1905, *Grant, U. S.*, Structural relations of the Wisconsin zinc and lead deposits: Econ. Geol., v. 1, p. 233–292.

1906, *Grant, U. S.*, Report on the lead and zinc deposits of Wisconsin: Wisconsin Geol. and Nat. History Survey, Bull. 14, 100 p., with atlas.

A series of papers containing valuable structural data. Grant notes that the gentle folds in the district most commonly have nearly west trends. He assigns the folds to "irregularities of deposition accentuated by folding". Notes the presence of the two main anticlinal folds crossing the district. Describing the pitching of the folds, he concludes "that this shows the district has been compressed somewhat by a force acting in an east-west direction as well as by one acting in a general north-south direction". He points out that the folds tend to be asymmetric toward the north. Recognizes two types of joints: regional joints that are vertical and inclined joints more common near the mines.

Notes the prime importance of the pitch and flat deposits, and first describes large disseminated deposits. Structural-contour and geologic maps show the general relationship of many ore bodies to synclines.

1906, *Bain, H. F.*, Zinc and lead deposits of the upper Mississippi Valley: U. S. Geol. Survey Bull. 294, 148 p.

In general, Bain's ideas regarding structure were in close agreement with those of Grant. In addition to the causes of the structure previously referred to by Grant, he includes a third factor—"the settling incident to the consolidation of the beds". Points out that more argillaceous material is present in the oil rock of the basins. Considers this shale to be local accumulations of argillaceous material in the depressions of the primary sedimentary irregularities. Concludes that the present basins are due to greater compactional consolidation of these local argillaceous deposits relative to the surrounding limestones.

Recognizes no faults. Attributes the pitches to a sagging of the beds, owing to differential compaction of the local "areas of oil rock shale."

1907, *Grant, U. S., and Burchard, E. F.*, Lancaster-Mineral Point folio: U. S. Geol. Survey, Folio 145, 14 p. and maps.

Contains geologic and topographic maps of the western portion of the Wisconsin part of the district. A restatement of Grant's structural views.

1909, *Hotchkiss, W. O., and Steidtmann, Edward*, Geological maps of the lead and zinc district: Wisconsin Geol. and Nat. History Survey, Supplementary maps (6).

Detailed geologic structure maps covering areas not surveyed by Grant but otherwise similar.

1914, Cox, G. H., Lead and zinc deposits of northwestern Illinois: Illinois Geol. Survey, Bull. 21, 113 p., 4 maps.

Structural views in essential agreement with those of Grant and Bain. Suggests that solution has played an important part in the development of flats and pitches, "probably in connection with oil rock slump". Notes that some of the ore bodies occur on the limbs of the folds and near the crests of anticlines. Points out that the zinc deposits do not directly underlie the joint-controlled lead deposits.

1914, Hotchkiss, W. O., Davis, R. E., and others, Special sheets, Wisconsin Geol. and Nat. History Survey and Wisconsin Mining School, 8 maps, unpublished.

Structure maps revising some of the areas covered by Grant. For the first time zinc-mine workings are shown, as well as the strike and dip of some of the controlling fractures.

1916, Shaw, E. W., and Trowbridge, A. C., Galena-Elizabeth folio: U. S. Geol. Survey Folio 200, 13 p.

Contains geologic and structure-contour maps of the two quadrangles, in Illinois. The folds are attributed to the following causes:

1. Original inequalities of the sea bottom.
2. Irregularities of deposition.
3. Vertical compression and subsequent slumping.
4. Actual mechanical depression by lateral pressure.

The authors regard the pitches as fractures not directly related, genetically, to the vertical joints. Recognize that the pitches dip outward from the basins and beneath the anticlines. Pitches, like the major folds, are attributed to compression and slumping, possibly acting simultaneously. No faults recognized.

1918, George, H. C., Wisconsin zinc district: A. I. M. E., Trans., vol. 59, p. 115–150.

This paper gives some pertinent details and variations of the structure of the zinc ore bodies. Suggests the basins are formed in part by solution and slumping owing to secondary alteration of the oil rock.

1920, Boericke, W. F., and Garnett, T. H., The Wisconsin zinc district: A. I. M. E., Trans., vol. 63, p. 213–243.

Contains fairly detailed descriptions of zinc ore bodies and their structure. Points out that the pitches are weak and steplike in the northern part of the district, but are strong and smooth-walled in the southern part. Mentions secondary alteration of the oil rock and the tendency for ore bodies to be alined along trends.

1926, Leith, Andrew, and Lund, R. J., The geology of the Monmouth mine in its relation to the origin of the lead and zinc deposits of the upper Mississippi Valley: unpublished B. A. thesis, University of Wisconsin, Madison.

Made the first attempt at detailed geologic mine mapping. Describes a well-marked series of minor, overturned, recumbent, and fan folds in the incompetent shale of the Spechts Ferry exposed in a drift, 920-foot long, in the Monmouth mine. The folds are accompanied by small reverse, normal, and thrust faults. The structures are considered to be a result of compressive deformation later and unrelated to the regional structures and fractures controlling the ore bodies.

1924, Spurr, J. E., Upper Mississippi Valley lead and zinc ores: Eng. and Mining Jour. (Press), v. 117, nos. 6, 7, p. 246–250, 287–292.

Considers the pitches and flats and vertical lead-bearing joints as individual parts of the same series of fractures. Notes the presence of minor faults, accompanied by folding and brecciation, controlling the ore bodies. These faults, he suggests, tended to flatten out into a bedding-plane fault along the incompetent Spechts Ferry shale member which "acted as a gliding plane between the upper and lower hard limestones". Considers deformation as the result of "dynamic compression" and, in part, due to "the presence of the ore solutions themselves".

Proposes that the areas of intense mineralized fracturing roughly outline and "overlies upward intrusions or protrusions of igneous rock which have never reached the surface". Subsidence and contraction took place producing the fissures, one normal to the trend of the buried intrusions, and one parallel to them. Considers that the larger folds have no direct relation to the ore bodies.

1929, Emmons, W. H., The origin of the deposits of sulfide ores of the Mississippi valley: Econ. Geol., v. 24, p. 221–271.

Like Chamberlin, he asserts that the LaSalle anticline, if projected, would extend northwestward through the center of the district. Suggests the presence of bedding-plane faults in the district.

1932, Leith, C. K., Structures of the Wisconsin and Tri-State lead and zinc deposits: Econ. Geol., v. 27, p. 405–418.

Defends and reiterates the views of Grant and Bain. Regards the formation of the pitches and vertical lead-bearing joints as the result of slumping, and considers that this collapse produced any minor faults that may be present in the district.

1934, *Scott, E. R.*, The structural control of ore deposition in the upper Mississippi Valley, lead-zinc district: unpublished M. A. thesis, Northwestern University, Evanston, Ill.

Scott made a careful study of certain synclinal basins near Hazel Green, Wis. Concludes that most of these basins are of a magnitude that excludes an origin by slumping, but that they were formed, for the most part, by deformation which has also localized the ore bodies that lay within them. First notes the presence of the linear northwest-trending basins, in addition to the east-trending synclines. Believes that solution of the calcareous beds of the oil rock was a cause of some of the minor structural features.

Notes the presence of faults, mainly bedding-plane slips, plus some steeply inclined faults, which he considers to be chiefly normal faults. Attributes these inclined faults to regional deformation followed by slumping.

1935, *Behre, C. H., Jr.*, The geology and development of the Wisconsin-Illinois lead-zinc district: Guidebook, 9th Ann. Field Conf., Kansas Geol. Soc., pp. 377–382.

1937, *Behre, C. H., Jr.*, Bedding plane faults and their economic importance: A. I. M. E., Trans., v. 126, p. 512–529.

Concludes that the basins and faults are dominantly of tectonic origin, which "might well have been initiated or intensified" by compaction of the oil rock. Notes the existence of pre-mineralization bedding-plane, reverse, and normal faults. Concludes that some of the pitches are reverse faults, and that the flats are bedding-plane faults directly connected with the pitches. He relates many of these faults to thrusting in nearly horizontal beds under a light overburden.

1937, *Behre, C. H., Jr., Scott, E. R., and Banfield, A. F.*, The Wisconsin zinc district, preliminary paper: Econ. Geol., v. 32, p. 783–809.

A summary of their views with additional pertinent data. They conclude:

"Structurally the ores are chiefly near the flanks of basins. Brittle dolomites are the most favored host rocks and the ores are clearly for the most part fracture fillings. Mineralized faults of small displacement are common and pass through the otherwise relatively impervious 'oil rock', at least in some cases. The faults and folds are both believed to be the result of tectonic movements."

Behre, Scott, and Banfield give several examples of reverse and bedding-plane faults. Conclude that the known reverse faults dip toward the axis of the syncline in which the ore is found and that the normal faults dip away from the axis. They note that the faults generally strike parallel to the fold axes and are commonly identical with pitches and flats, and that mineralization is sparse in the hanging wall.

1939, *Bastin, E. S., Behre, C. H., Jr., and others*, Contributions to a knowledge of the lead and zinc deposits of the Mississippi Valley region: Geol. Soc. Amer., Special Paper, no. 24, 153 p.

This useful publication gives a summary of all the viewpoints of the regional and local structures of the upper Mississippi Valley district. Emphasizes the marked similarity in magnitude and type of structure of the district to that of the other lead-zinc mineralized districts in the Mississippi Valley.

1947, *Willman, H. B., and Reynolds, R. R.*, Geological structure of the zinc-lead district of northwestern Illinois: Illinois Geol. Survey, Report of Investigations, no. 124, 15 p., 7 maps.

They relate the arcuate ore bodies to synclines and the linear ore bodies to probable shear zones of vertical joints. These pre-ore structures are considered to be the result of tectonic deformation. Consider that the narrow local synclines, and the small faults and fractures present in the vicinity of the ore bodies, were produced by collapse following solution of the strata during ore deposition. Locate and describe several synclines, of which the Galena and Vinegar Hill synclines are most important.

PROPOSED INTERPRETATION

Study of the geology of the upper Mississippi Valley zinc-lead district strongly suggests that most of the structures observed are the result of one main period of regional tectonic deformation, although earlier periods of lesser deformation are known. This regional deformation, though far from intense, was sufficient to produce the major and minor folds, faults, fractured zones, and joints. Since the main period of deformation the upper Mississippi Valley district has been slightly uplifted and tilted.

OROGENIC DISTURBANCES IN THE NORTH-CENTRAL STATES

Structures developed in the Precambrian basement apparently had considerable influence on the post-Algonkian type structural features of the Midwest. Inasmuch as the entire region of the North-Central States is underlain by covered or exposed shield, the areas of structural stability or weakness in this shield tend to be reexpressed in the overlying Paleozoic sedimentary rocks.

Early features that bear on the regional structure of the North-Central States resulted from the major orogenic disturbances that developed the Lake Superior syncline in the Proterozoic era. During this disturbance lava flows were extruded into the Lake Superior basin and were accompanied by the deposition of sediments. The rocks within the syncline were folded, and granitic rocks were extensively intruded to the south of the Lake Superior syncline. In northern Michigan these Precambrian deformations resulted in the folded and faulted areas of ferruginous sediments of the Iron River-Crystal Falls and Marquette iron-bearing districts. In central and eastern Wisconsin similar, smaller areas of folded Huronian rocks are found in prominent mounds and ridges at Black River Falls, Wausau, and Baraboo, and the covered areas (known by subsurface studies) near Fond du Lac and Waterloo, Wis. (Thwaites, 1931, p. 719–750). The general trend of these Precambrian folds is between N. 70° E. and due east. These structures trend nearly normal to many of the later midwestern structures. By the end of Precambrian time the entire area had become relatively stable and rigid, and then was widely uplifted and extensively eroded. Certain local zones of crustal weakness apparently still existed as major lineaments along which activity continued during later periods of deformation. Such zones of weakness have been postulated, for example, along the Wisconsin arch, the Kankakee and Cincinnati arches (Pirtle, 1932, p. 145–152), the La Salle anticline (Cady, 1916, p. 85–179), and the Rough Creek-Shawneetown fault zone (Clark and Royds, 1948, p. 1728–1749) of southern Illinois. Similar zones have been postulated along the borders of all the major basins of the Central States; these zones of weakness join to form northeast and northwest zones that define and border the basins (Keith, 1923, p. 309–380). The basins are underlain by relatively rigid, stable blocks. The major structural features, according to Keith, lie either at the intersections of two or more major zones of weakness, giving rise to domes, or as zones of stability, resulting in basins. By this hypothesis the Michigan, Illinois, and Forest City basins are depressed, relatively strong crustal blocks, whereas the Cincinnati, Kankakee, Wisconsin, and Mississippi Valley arches and the La Salle anticline mark zones of basement weakness and uplift. Keith postulated that the repeated orogenic movements have been operative along the anticlinal zones of basement weakness throughout a large part of geologic time and that simultaneously the more rigid basin areas tended to be depressed.

Some of the domes and basins of the North-Central States may have been initially developed before the Paleozoic era (Pirtle, 1932, p. 150). The Lake Superior basin curves around the north end of the Wisconsin dome and is directly connected by shallow saddles with the Forest City basin to the southwest and with the Michigan basin to the southeast. Some thickening of the earliest deposited Paleozoic sedimentary rocks within some of the major basins indicates a slightly greater depression in these areas.

At the end of Precambrian time widespread uplift above sea level occurred, followed by widespread erosion throughout the North-Central States. The surface of the region was reduced by erosion to a surface in late maturity, and moderate relief. The region was depressed again at the end of the Middle Cambrian, and sediments, mainly sandstones, were deposited throughout the entire region, including the areas of later major regional uplift, such as the Wisconsin dome. The widespread sedimentation continued until the end of the Early Ordovician. At that time a second widespread uplift developed and the lower Paleozoic strata were widely eroded. Folding commenced in certain areas of crustal weakness, such as along the Kankakee arch in Illinois (Willman and Payne, 1942, 377 p.; Ekblaw, 1938, p. 1425–1430), the northeastward-trending Marseilles anticline in north-central Illinois, and the Wisconsin arch. This is the period of major uplift of the Kankakee arch.

Depression and widespread marine deposition occurred during the remainder of the Ordovician period except for slight uplifts of the Marseilles anticline (Willman and Payne, 1942, 377 p.) and the beginning of the rise of the Cincinnati arch, far to the southeast, in the Middle Ordovician (Pirtle, 1932, p. 145–152). The lack of thinning of the Ordovician sedimentary rocks as they approach the Wisconsin arch and dome suggests that these structures were entirely covered by Middle and Upper Ordovician sediments (Trowbridge, 1934, p. 519–528). At the end of the Ordovician a slight local uplift of the Marseilles anticline and Kankakee arch took place in north central Illinois (Willman and Payne, 1942, 377 p.; Ekblaw, 1938, p. 1425–1430).

Widespread marine deposition continued in the Silurian period, except perhaps over the crest of the Wisconsin dome, which may have been above sea level at this time. However, this is not certain, as the Silurian seas may have covered the entire State of Wisconsin. At the end of the Silurian the region was uplifted somewhat and eroded. The Marseilles anticline and very probably the Wisconsin dome were also uplifted. Probably the Wisconsin dome was never completely covered by the sea after the end of the Silurian period.

After the post-Silurian erosion interval Devonian seas advanced over the region. Probably they did not cover the area of the Wisconsin dome and arch, for the Devonian strata thin rapidly toward their outcrops surrounding the dome. Beginning in the Michigan basin during the Silurian, and in the other basins during the Devonian, depressions continued throughout the Paleozoic era. At the end of the Devonian, local uplift, folding, and erosion occurred in central Illinois and Iowa (Keith, 1923, p. 309–380).

During the periods of development of the major structures of the region another low northward-trending anticline, comparable to the Wisconsin arch, was formed along the Mississippi River between the Illinois and Forest City basins (fig. 12). This anticline, called the Mississippi River arch (Howell, 1935, p. 386–389), possibly joins the Savanna-Sabula anticline in the area southwest of Sabula, Iowa. The Savanna-Sabula anticline apparently was formed at about the same time.

Following the Devonian erosion interval, Mississippian sediments were deposited in the Central States, except probably over the Wisconsin dome and arch. In the zinc-lead district these sediments, if present, were thin. At the end of the early Mississippian the folding of the LaSalle anticline began (Cady, 1916, p. 85–179).

Deposition of Mississippian strata was then renewed, and continued until the end of the period. The first period of major regional deformation, uplift, and erosion since the end of the Early Ordovician developed at the end of the Mississippian. Uplifts and slight folds were widely developed and affected all the major anticlinal areas.

The post-Mississippian period of diastrophism was followed by regional depression, and the deposition of Pennsylvanian sediments, particularly in the major basins. The Wisconsin dome and arch probably remained as land areas, though a thin veneer of Pennsylvanian sediments may have been deposited in the upper Mississippi Valley mining district. During the Pennsylvanian at least one, and possibly three periods of renewed uplift and folding, occurred along all the major anticlinal areas, followed by renewed deposition. As the Pennsylvanian sedimentary rocks are also appreciably deformed (Payne, 1939, p. 171–173), a period of major deformation occurred, probably the most important of all. This period of deformation possibly is related to the last stages of the Appalachian and Ouachita orogenies, which took place in late or post-Pennsylvanian times. Owing to the lack of Pennsylvanian and post-Pennsylvanian sedimentary rocks in the upper Mississippi Valley region, this deformation cannot be dated more exactly than probably post-middle Pennsylvanian and pre-Cretaceous in age (Clark and Royds, 1948, p. 1728–1749). This late deformation was widespread throughout all the North-Central States. The deformation probably produced the final major uplift of the principal anticlines and domes, the folding and faulting in the basins, the development of the major fault zones of southern Illinois and Kentucky, and is generally considered as the culmination of late Paleozoic deformations in the North-Central States. The structures of the upper Mississippi Valley zinc-lead district probably had their origin during this general orogeny. Keith (1923, p. 308–380) concluded that this orogeny was caused by the transmission into the North-Central States of the compressional forces that also produced the Appalachian and Ouachita Mountain systems. Although much of this diastrophism resulted in simple vertical uplift and depression along the major lines of arching and downwarping, it was accompanied by considerable shortening induced by lateral compression, particularly along the margins of the basins. The upper Mississippi Valley district lies near the margins of both the Illinois and Forest City basins (fig. 12), and it therefore can be inferred that the folds of the district are similar to drag folds formed on the rims of gentle basins by lateral compressive forces. Such forces in the basement rocks apparently acted inwards toward the basin centers, and acted contrary to the relatively outward-directed thrust in the overlying crust of Paleozoic strata as the basins were downwarped. The magnitude of the structures of the district is of the same degree as similar structures produced elsewhere in the North-Central States, where the structures have very similar patterns of faulting and cross-folding (Willman and Payne, 1942, 377 p.; Pirtle, 1932, p. 145–152).

The scarcity of post-Paleozoic rocks in the North-Central States makes it impossible to determine much about deformations later than that era. About all that can be stated with any certainty is that during or shortly after the late Paleozoic deformation the entire region was uplifted by epeirogenic movements and that it remained above sea level throughout most the rest of geologic time. In the Cretaceous period, a sea advanced eastward from the Rocky Mountain geosyncline, and deposited a thin veneer of sediments in Iowa and Minnesota, and a second arm of the sea in the Mississippi embayment advanced northward into southernmost Illinois. Later these areas rose again, and the seas retreated to complete the cycle. Probably slight uplifts and tilting of the North-Central States took place during the Pleistocene, owing to the minor adjustments caused by the weights of the advancing and retreating ice sheets.

In 1909 a slight earthquake of fairly deep focus shook parts of northern Illinois and southern Wisconsin (Udden, 1910, p. 132–143). This tremor, evidence of continuing slight adjustments in the basement, was centered partly along the axis of the La Salle anticline and partly along an eastward cross-trend developed parallel to the major folds in southernmost Wisconsin. The T-shaped form of the area most severely shaken by the quake suggests that the movement was due to adjustment along the basement fractures that underlie these structures.

DEVELOPMENT OF THE STRUCTURAL FEATURES IN THE NORTH-CENTRAL STATES

The basins and domes of the North-Central States were apparently initiated in the early Paleozoic and principally developed in late Paleozoic time. This late Paleozoic movement corresponds closely to the period of compression and shortening expressed in the Appalachian orogeny. During this complex orogenic period the folded Appalachian and Ouachita Mountain systems were the results of repeated compressive movements at right angles to these structural belts. Some of these forces were transmitted through the basement rocks into the Midwest area compressing this area between the stable Precambrian shield to the north and the orogenic belts to the east and south. Apparently these compressive forces were important factors in the principal development by lateral shortening and rotational movement of the major domes and basins and produced many minor folds, faults, and flexures within them. Whereas, by contrast, simple vertical forces producing uplifted domes and depressed basins would have resulted in the lateral distension of the rocks of the region, but the lesser structures provide abundant evidence of having been produced by compressive lateral movements. Therefore, the major uplifts of the Wisconsin dome and related arches, and the Michigan, Illinois, and Forest City basins probably took place under conditions of general shortening and lateral compression related to the Appalachian-Ouachita orogeny.

ORIGIN AND DEVELOPMENT OF THE DISTRICT STRUCTURES

In this discussion of the origin of the structures the directions along which the forces acted are given in some sentences for simplicity's sake in terms of a single cardinal direction—that is, "north-directed compressive forces" or "forces acting from the southwest"—in place of the accurate but mouth-filling terminology "north-south-directed compressive forces" or "compressive forces acting parallel to a northeast-southwest direction". It should be understood in this discussion that all tectonic forces are balanced by or interacted with an opposing force or a combination of forces either in direct opposition or in force couples. Some of the force couples operated parallel to the horizontal plane of reference to form such structures as vertical shear faults, and others operated in the vertical plane to produce folds and bedding plane faults by movements of the near-surface strata relative to those lying beneath.

Most of the folds, faults, and joints of the zinc-lead district were formed by the same tectonic forces that developed the major structures in the surrounding region. The development of the Wisconsin dome and arch to the north and northeast of the district, by successive vertical uplifts in the Paleozoic era, prevented a thick cover of sediments, particularly those of upper Paleozoic age, from being deposited in the district. This uplifted area, which contains a core of Precambrian basement rocks, may have acted as a buttress against which the surrounding areas of the basement and capping Paleozoic strata to the south and west were laterally thrust. The folds in the district are asymmetrical, and the greater inclination of the limbs towards the north and northeast strongly suggests that the lateral compressional forces acted principally in the north and south and to a lesser extent in the northeast and southwest directions. The thin shell of Paleozoic surface strata was thrust northward and northeastward relative to the underlying Precambrian rocks of the basement. The district folds were formed like drag folds along the rims of the gentle Illinois and Forest City basins as these large structures were formed by crustal downwarp. Most of the structures in the district seem to have been developed by these compressional forces. The mineralized area has thus been developed within a salient between the northern part of the Illinois basin to the south, and the eastern part of the Forest City basin to the west. Both major basins have apparently very similar diastrophic histories, being subjected to deformation at about the same successive periods and to the same degree. Their similar histories are shown by nearly like records of uplift and deformation in both basins, and by unconformities at approximately the same horizons in the stratigraphic sequence.

DEVELOPMENT OF STRUCTURAL FEATURES WITHIN THE DISTRICT

Most of the structures in the district were produced by a single general period of deformation. That this is a single period, rather than two separate periods, is indicated by the nature of the cross folding, by the fact that fracture systems curve without break from the east-trending folds into the northwest-trending folds, and by the arcuate fracture systems that completely enclose the noses of the canoe-shaped folds. The cross folds, which are parallel to the rims of the Illinois and Forest City basins, appear to have been developed by a combination of compressive forces, a northward movement in the Paleozoic strata from the Illinois basin, and a similar, lesser shove northeastward from the Forest City basin. These convergent forces resulted from simultaneous compression that affected both basins. The near surface crust of strata was thrust outward from the basin centers towards the rims relative to compressive forces that were transmitted inward through the underlying basement into the basins from the north and northeast as the basins were downwarped. The crustal shortening, produced by the relatively downward movement of the basins under compression, was probably equivalent to 3,000 to 5,000 feet. Quantitatively the amount of lateral shortening expressed by the folds and faults within the district is probably less than 2,000 feet, and it exhibits an amount of crustal shortening that might be produced along a rim of a shallow compressional basin. The Illinois basin is nearly twice as deep as the Forest City basin and has much more steeply dipping sides. Likewise the minor folds and faults of the Illinois basin are much more numerous and more strongly developed, and considerably more lateral shortening in the near-surface rocks has resulted. Therefore the folds produced by the differential drag between the near-surface strata and the relatively inward-moving basement rocks would be stronger along the margins of the Illinois basin than along the margins of the Forest City basin.

The Savanna-Sabula anticline, which lies between the Illinois basin and the district, has a steeper north limb that indicates it is a drag fold developed near the northern edge of the Illinois basin. Similarly, the northwest-trending Allamakee anticline (fig. 12), which is northwest of the district has a steeper northeast limb and apparently was formed by a tectonic force directed northeastward from the Forest City basin.

The district structures were mainly produced by north and south directed compressive forces related to the Illinois basin, combined at about the same time with similar lesser forces related to the Forest City basin. Except in the northwest part of the district, where the first-order Mineral Point anticline has a northwesterly trend, the force components directed northeastward from the Forest City basin may have acted essentially as a static retaining force. These forces produced the northwest folds by preventing elongation and tension along the axes of the east-trending folds developed by the major north-directed forces, combined with some rotation by local force couples. The northeastward-directed forces may have caused sufficient lateral shortening to produce the less numerous northwest folds which are more commonly found in the western half of the district.

The Wisconsin dome apparently acted as a resistant area against which the lateral compression in the north and south and in the northeast and southwest directions acted to produce the folds of the district. The surface of the Precambrian rocks, where exposed to the north of the district, is not a peneplained surface but one of late maturity which contains several monadnocks of considerable relief—for example, the Baraboo Hills and Rib Mountain near Wausaw. Possibly the Precambrian surface in the district contains similar irregularities, but their existence remains to be established. Very minor depositional irregularities or thinning of the beds are known to exist anywhere within the beds above the St. Peter sandstone. For example, the Spechts Ferry shale member uniformly thins eastward from 8 feet thick in Iowa to complete absence of the unit in the eastern part of the district. Probably any existing Precambrian monadnocks were completely and deeply buried by the time the Middle Ordovician seas covered the mineral district. This very uniform deposition is positive evidence that the deformation of the district, producing the present structures, is post-Silurian. However, deeply buried sub-Cambrian irregularities probably do exist, as well as others in the Prairie du Chien group, and may have played a part in developing the structural pattern of the district. Any large upward protruding, resistant Precambrian hills would tend to be expressed in the near-surface structure. Initial dips of the bordering Paleozoic sedimentary rocks might give rise to slight domes, and such local areas of stability would later resist lateral compression when the overlying sediments were deformed. For example, a stable area or buried monadnock actually may underlie the area of very slightly deformed rocks in the northern part of the district that is bordered and partly surrounded by the first-order Mineral Point anticline. Geophysical studies are in progress to determine, if possible, the configuration of the pre-Paleozoic surface of the upper Mississippi Valley district.

ORIGIN OF THE FOLDS

The first-order folds of the upper Mississippi Valley zinc-lead district are of such magnitude and linear extent—traceable up to 40 miles (pl. 8)—as apparently to exclude any other hypothesis of their origin than regional lateral compression. Their amplitudes range between 100 and 200 feet, and data from outcrops and recent deep drilling (Heyl, Lyons, Agnew, 1951, p. 7–9, 16) in ore bodies have shown that the larger third-order folds, at least, continue into the Cambrian strata. The degree of folding does not decrease except for the amount equal to the local thinning of some of the rock units by the ore solutions (fig. 40). The trends of these folds in a general easterly direction and also less common northwesterly trends of parts of these folds are indicative of the common origin of the east- and northwest-trending folds. The steeper north and northeast limbs of all the anticlinal folds indicate their formation by northward- and northeastward-directed lateral compressive forces. The south and southwest loci of these forces in the basins are also strongly indicated by the progressive decrease in the size and amplitude of the structures from south to north. The progressive northward decrease in deformation is exhibited not only by the first-order folds, but also by the second- and third-order folds, and by the faults as well.

Throughout most of the district both the east-trending and northwest-trending second- and third-order folds exist, but the northwest-trending folds are more abundant and better developed nearer the Forest City basin. The two lesser fold groups form a rough rhombic network intersecting at an angle of about 70° (fig. 18).

The fold, fault, and joint patterns are regular and consistent throughout the district, which strongly suggests their common origin by a general regional com-

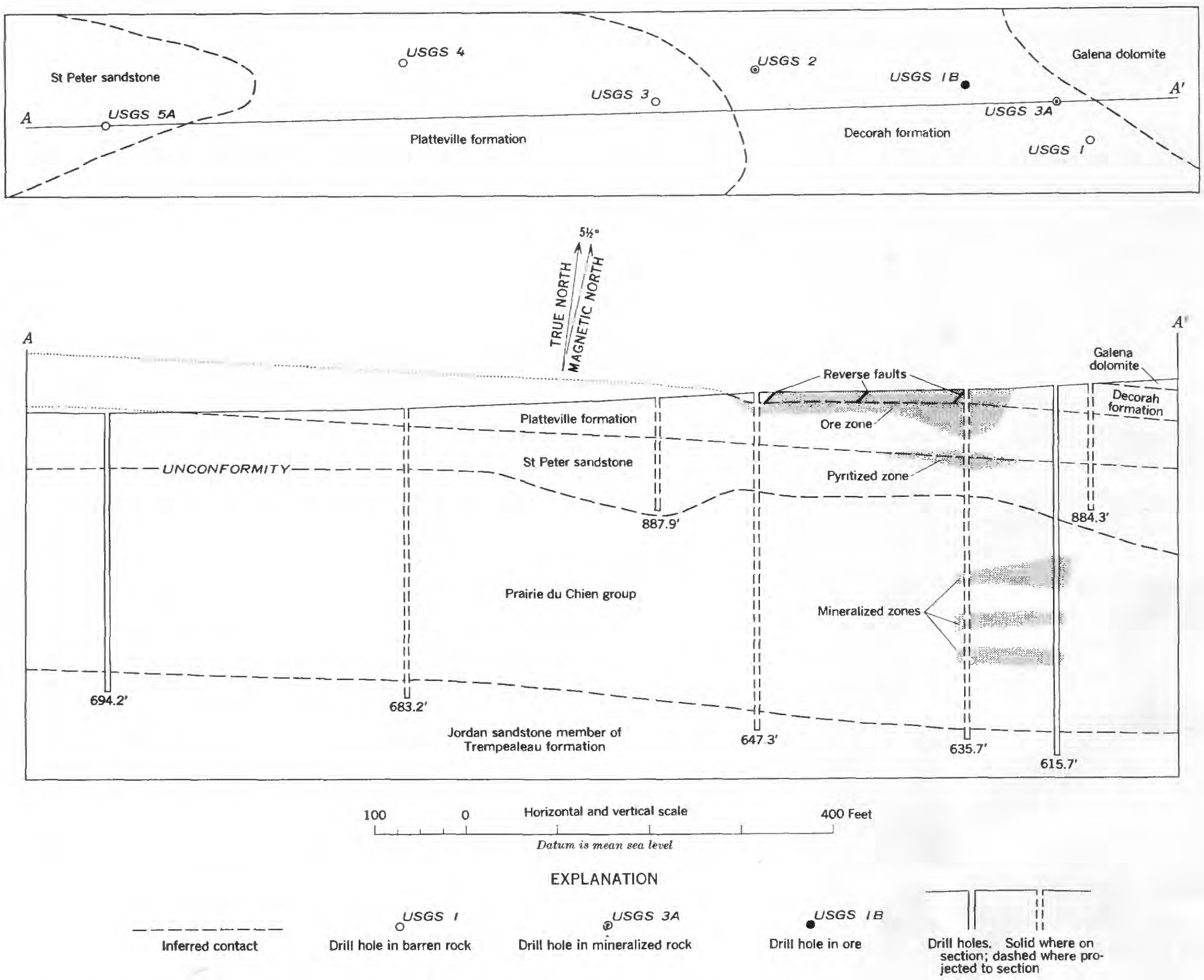


FIGURE 40.—Section across the steeper north limb of the Mineral Point anticline at the Crow Branch Diggings (S½ sec. 22, T. 5 N., R. 1 W.). The syncline is shown by the principal formation boundaries cut by the Geological Survey's drill holes. Note that the syncline developed in the base of the Decorah formation is closely followed by the top of the underlying Jordan sandstone member except for local solution-thinning in the upper ore zone. Note also that the position of the lower sphalerite mineralized zones in the Prairie du Chien group is beneath and slightly to the east or synclinal side of the upper ore zone.

pression rather than by local conditions of sedimentary irregularities, initial dips, differential compaction, or simple slumping. The smaller folds of the upper Mississippi Valley district are very similar in pattern and magnitude to those in other areas of incipient folding, like the Appalachian Plateau, as pointed out by Bain (1906, p. 38–43), and in north-central Illinois as described by Willman and Payne (1942, 377 p.).

The lengths (2 to 10 miles) and amplitudes (40 to 100 feet) of most second-order folds are large enough to be much more easily explained by lateral compression than by other causes. Even the third-order minor folds are considered, for the most part, to be simply the result of lateral compression. They show a marked continuity of trends and patterns with the larger folds. The amplitudes of the minor folds suggest that many of them are greater in size than would be expected from slumping due to solution. However, undoubtedly, solution thinning of the beds in the vicinity of ore bodies has locally accentuated some of the smaller folds, perhaps as much as 10 or 15 feet in places. Very shallow basins, a few hundred feet long, are found in the beds above parts of a few ore bodies in the southern part of the district where solution-thinning has been unusually great. For the most part no marked difference was observed in either pattern or amplitude of the lesser folds in the mineralized areas and of the flexures in barren areas.

From the foregoing evidence the writers conclude that the lesser folds were, like the greater folds, a result of the regional tectonic deformation of the rocks in the district. The degree and trends of folding in a given area are possibly caused in part by the resistance of upward-projecting, buried, local ridges of basement rocks. Marked irregularities of original deposition, present only in the lower pre-Middle Ordovician sediments, seem to have been an unimportant factor in the development of the district structures.

ORIGIN OF THE FAULTS

Most of the numerous faults in the district have been caused by regional tectonic forces. But in some mineralized areas the dissolving action of the ore-solutions or of meteoric water have formed minor fractures and small down-dropped blocks, which simulate tectonic fault conditions. These blocks are fairly common in the lead-bearing joint deposits above water table, and minor breaks resulting from solution are locally observable in the zinc mines.

Most of the major faults caused by compression are related to the general deformation. The reverse faults along the steeply-dipping north limbs of the first-order folds have a displacement (20 to 40 feet) and a length that exclude other causes than compressional forces. Likewise, the shear faults, as the Liberty mine fault at Meekers Grove and the Mifflin fault, are of such magnitude and probable horizontal displacement that no other hypothesis of origin appears tenable.

The shear faults at the Liberty mine and at Mifflin are situated in areas of unusually intense deformation, and both lie less than 2 miles north of first-order folds. Both faults are close to a sharp bend in the adjacent major fold—an area of considerable variation in the directions of horizontal adjustment of the rocks. The Liberty mine fault (fig. 23) displaces 25 feet horizontally, the arcuate reverse fault that forms the pitch in the Liberty mine. The Liberty mine fault is therefore assumed to be a relatively late fracture. It was formed later than the reverse fault it displaces but earlier than the deposition of the similar unsheared ore veins in both fractures. The northward bend of the Meekers Grove anticline to the south and southeast (pl. 3) apparently caused considerable lateral northward pressure against the rocks to the east of the fault relative to those to the west. Relief from lateral pressure seems to have been easier in the horizontal plane than in the vertical, and consequently the rocks failed along one of the preexisting N. 77° W. joints that had been developed in the center of the Liberty mine syncline. The rock mass to the northeast of the fracture moved relatively northwestward to produce the vertical shear fault.

The Mifflin fault (pl. 2) strikes N. 40° W. across the main syncline north of the Mineral Point anticline (pl. 8). This fracture has a measured vertical component of displacement of at least 50 feet in one place along the fault trace, but its possible horizontal component may be as much as 900 or 1,000 feet, the rocks on the southwest side of the fault having moved northwestward relative to those on the northeast side. The fault plane is not visible at any point, but from the nearby subsidiary fractures it probably is nearly vertical. Like the Liberty mine fault the evidence suggests that the Mifflin fault is later than the reverse faults but is pre-ore in age. This relationship is borne out by the apparent displacement of about 900 feet of the O. K. mine-Slack mine fracture systems, and because the ore body of the Old Slack mine is localized by the Mifflin fault zone. The N. 40° W. strike is parallel to the northwest J_3 joints, and the fault may have developed along one of these shear joints as the initial fracture. Therefore, the Mifflin fault is probably contemporary in age with the Liberty mine shear fault and has a similar origin. About 4 miles to the west of the Mifflin fault the Mineral Point anticline turns sharply to the north for several miles (pl. 8). Possibly the compressive forces in the south and north directions were able to act considerably farther to the north in the area west of the fault as compared to that to the east. The northward pressure to the west forced the rocks west of the fault northwestward.

The known major reverse faults are restricted to the steeper north limbs of the larger anticlines that cross the district. The fault planes all dip toward the south and southwest to form typical high-angle thrust faults produced by forces directed toward the north and south and toward the northeast and southwest. The fact that these faults developed in a very early stage of folding apparently is a result of the compressive forces acting beneath a thin overlying sedimentary cover at the time of deformation. Under these conditions the competent brittle dolomites of the area would early reach the elastic limit and fracture at a very early stage in the folding. The result differs from that produced in rocks compressed under a heavy overburden, because then the elastic limit is reached much later in the deformation after the rocks are much more tightly folded. Therefore these reverse faults are apparently the shear fractures in the vertical plane formed by the lateral compressive forces acting under a relatively light cover within the brittle rocks of Ordovician age after the slight degree of folding before fracturing had taken place. Except for their larger displacement and their probable extension to or into the basement rocks, these reverse faults are considered to be similar to the smaller reverse faults that are so abundant along the limbs of the smaller folds in the district.

The smaller faults are most common in zones on the flanks of the smaller folds. They are most abundant on the flanks of synclines (fig. 41), less abundant on the flanks of anticlines, and are rarely associated with monoclines. The fracture zones not only follow

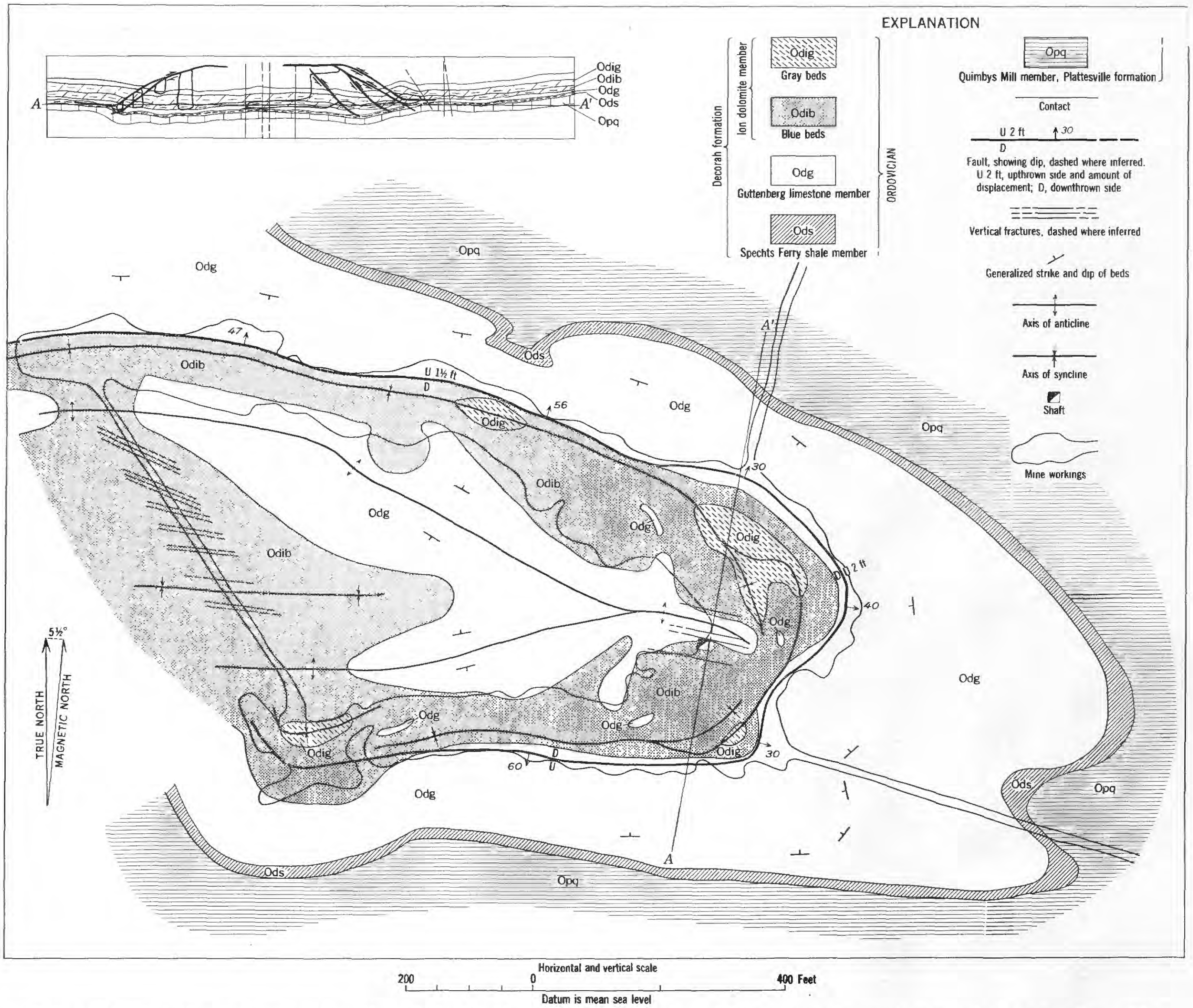


FIGURE 41.—Geologic mine map and section of the Hoskins mine, New Diggings, Wis.; a typical arcuate ore body in a syncline. The geologic data and intepretation are shown as if plotted on a horizontal section near the mine floor. For further details see plate 12.

along the flanks of the folds but many swing around the plunging ends to form the arcuate fault zones that are so numerous in the district. Where this tendency toward arcuate fractures reached completion, the plan of the fault zone around the fold is elliptical; an example of a fault zone around an anticline is the Coker No. 2 ore body (fig. 27). Many of the northwest-trending synclines, in which faults are located, are relatively linear and narrow. Hence the faults on the synclinal flanks are closer to the fold axes than the fault zones of the wider arcuate folds. Nevertheless, the central area along the fold axis of the linear synclines is generally less disturbed than are areas to either side on the flanks, where the main reverse faults are located. Good examples are the Graham-Ginte mine (fig. 42 and 43) in northern Illinois and the Kennedy mine at Hazel Green, Wis. (fig. 29). Typical arcuate fault zones exist in the northwest folds (pl. 5, NE¼ sec. 8, T. 1 N., R. 1 E.), although they are less common than the linear fault zones; straight-line fault zones are found in a few places along the east- and northeast-trending structures (pl. 5, N½ sec. 30, T. 1 N., R. 2 E.).

The fault zones consists of a complex system of bedding-plane faults which are combined with reverse faults and to a lesser extent with normal faults. The reverse faults, without exception, appear to be the result of compression rather than collapse, and most reverse faults dip toward the bordering anticlinal areas. The bedding-plane faults are probably in part compressional, combined with some tensional action owing

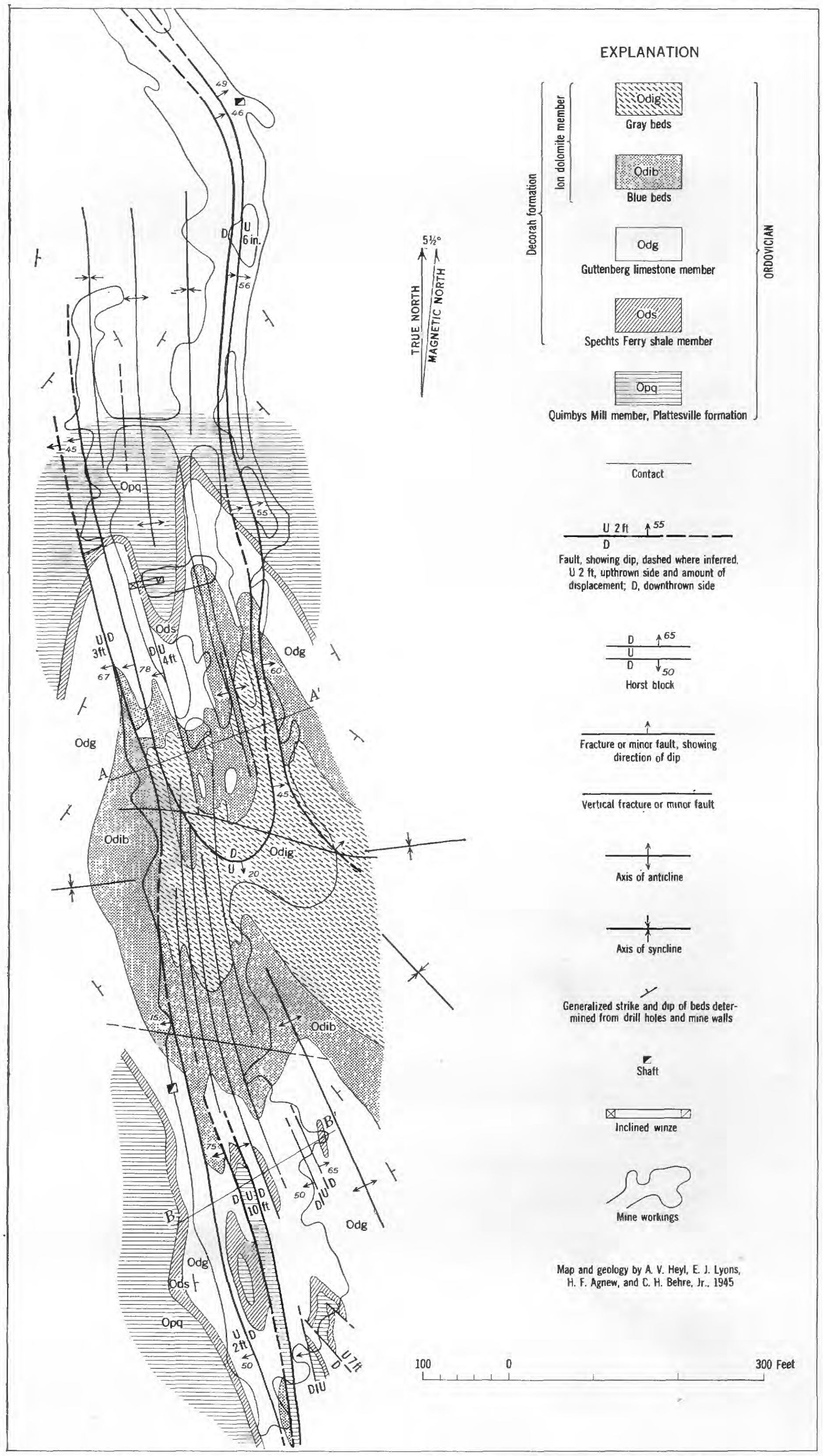


FIGURE 42.—Geologic mine map of the Graham-Ginte mine, 3 miles north of Galena, Ill.; a typical linear ore body in a northwestward-trending syncline. Sections *C–C′* and *E–E′* are shown in figure 43. Geology is plotted on a horizontal section at the level of the mine workings at 610 feet altitude above sea level. For further details see plate 20.

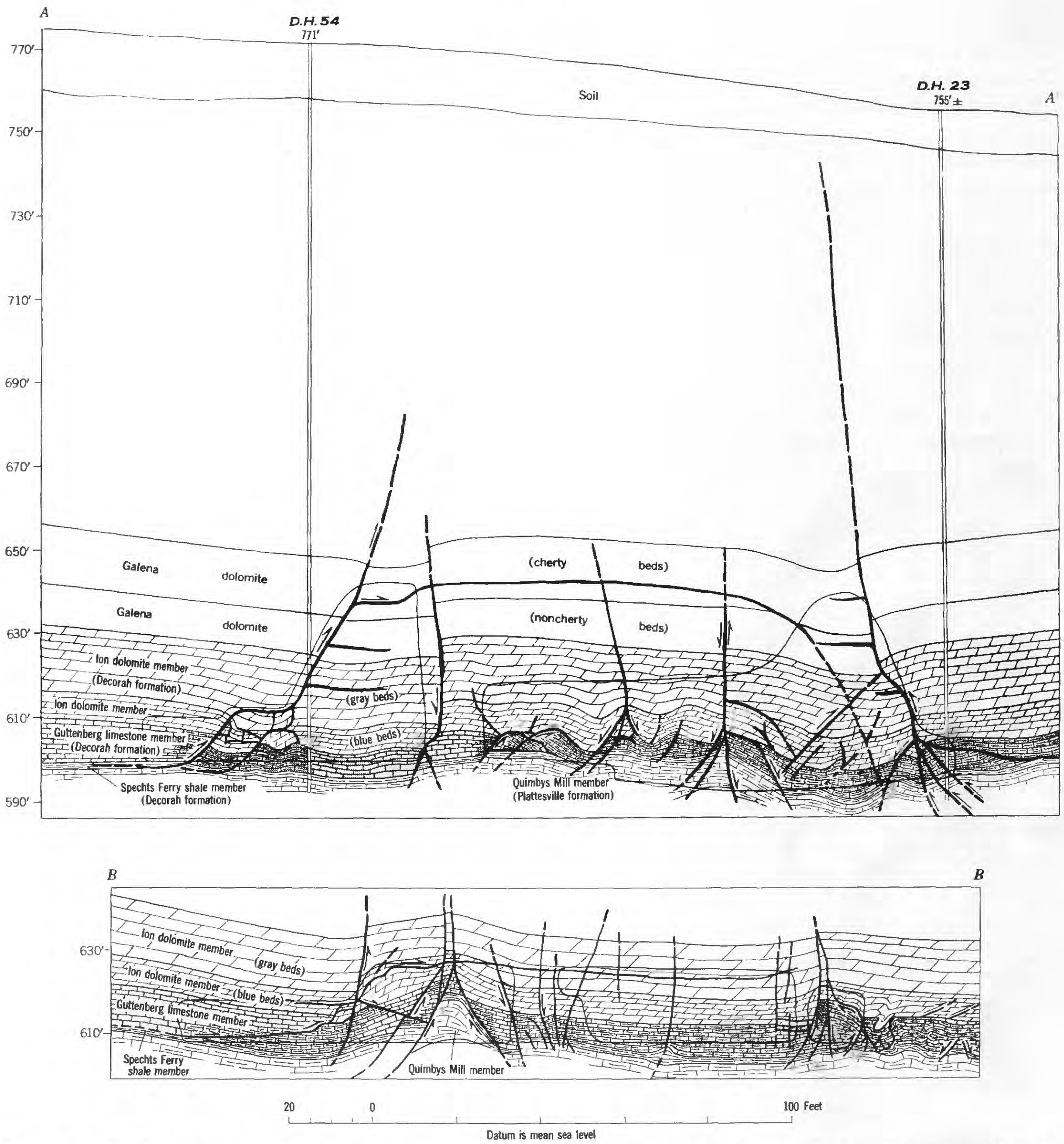


FIGURE 43.—Section C–C′ across the central part and section E–E′ across the south part of the Graham-Ginte mine. Note the structural complexity and local thinning in the incompetent beds of the lower Decorah (so-called oil rock and clay bed). For further details see plate 20.

to hinge lifting through local tension caused by the compression.

All the faults therefore seem to have resulted primarily from the lateral compressive tectonic forces that acted in a given fold. The fault zones apparently originated on the flanks of the folds where the dips are the steepest and the tendency to fracture is the greatest. The normally brittle beds of the Galena dolomite and the Decorah formation tended to fracture during the development of the incipient folds beneath a relatively light cover of rocks. Furthermore, about 20 or 30 feet of relatively incompetent beds are present above and below the contact between the Decorah and Platteville formations. These rocks consist of interbedded carbonaceous shales and thin layers of sublithographic limestones: the Guttenberg limestone member ("oil rock"), underlain by a few feet of soft, plastic green shale known as the Spechts Ferry shale member ("clay bed")—respectively the middle and lowest members of the Decorah formation—and the Quimbys Mill member ("glass rock") member of the Platteville formation, similar to the Guttenberg in lithologic character. The shaly parts of these rocks flowed plastically under the pressure of the tectonic forces; it was in these incompetent members, particularly in the Spechts Ferry, that the tectonic stresses produced bedding-plane movement, and developed bedding-plane faults on the limbs of the folds. The first movement was due to flexing of the beds, was very slight, and appears to have consisted, as expected, of the beds above the plastic layer having moved toward the anticlinal axes (figs. 44 and 45). The elastic limit was reached in an early stage of the folding owing to the light overlying cover and the brittle nature of the principal deformed beds. The principal bedding-plane movement was directly related to compression and began after the elastic limit of the soft plastic layers was exceeded. This compressive action reversed the direction of bedding-plane movement and caused zones of squeezing and drag folds in the incompetent layers; the relief on the margins of the folds tended to be toward the synclines and upward. When the force was sufficient, an inclined fracture or zone of fractures began to form in the overlying competent beds along a shear plane at about 45°. As a result of the outward and upward thrust directed from the anticlinal areas by the compressive forces, this shear plane was developed dipping towards the anticlines as an incipient reverse fault. Nearly continuous shear fractures were formed obliquely upward across the beds, and these faults joined with the bedding-plane fractures to form a steplike combination of the planes of movement. As the process continued, inner or footwall fractures were developed down from each of the steps and up from the so-called clay bed, to form eventually a shear zone in which parallel bedding-plane faults and reverse faults constitute a rhombic pattern in cross section.

ORIGIN OF THE JOINTS

Like the folds and faults, the joints appear to have been formed by compression during the same period of regional tectonic deformation. They fall into two groups, apparently developed differently.

1. The vertical joints directly related to the regional deformation.

2. The inclined joints, indirectly produced by the regional deformation but directly related to the local folds and the reverse faults.

The vertical joints consist of two types, essentially east-striking tension joints and northeastward- and northwestward-striking shear joints forming a pair. The fairly constant trends of each of the three joint directions and continuity of the joints throughout the district indicate that their formation is very likely the result of forces which, because of the orientation of the joints, acted in the north and south directions. The evidence for the origin of the joints is as follows.

1. The vertical joint pattern is similar throughout the district; most joints fall into three groups striking (1) east, J_1; (2) N. 20°–30° E., J_2; and (3) N. 20°–40° W., J_3.

2. The east-striking J_1 joints are long now-open tension fractures. The great traceable lengths, smooth walls, and constant strikes of the east-striking joints suggest that they were originally formed as compression joints at right angles to the north or south direction of the main compressive force. Later the joints were opened to form tension joints by the relaxation of the rocks when the compressive force died out.

3. The northeast (J_2) and northwest (J_3) joints are tight shear fractures forming a shear pair bisected in the acute angle by the north-direction line of the main tectonic forces.

4. That all the joints may have been developed in the fairly early stages of the deformation is suggested by the apparent localization of some of the northwest folds along major northwest joints that seem to have acted as a zone of weakness aiding initial folding.

5. The joints were already formed before the end of the deformation, as they were the loci of lead sulfide mineralization near the end of the period of deformation. Marked shearing of the galena veins along some of the northeast- and northwest-striking joints indicates minor post-ore shearing movements.

6. The pattern of the joints is essentially the same as normally developed in regions of lateral compression, consisting of a shear pair of joints bisected by the plane parallel to the direction of principal lateral force (north in this instance) and of tension joints essentially at right angles to the force direction.

7. The direction of active force indicated by the joint relations is the same as the general northward movements that produced the folds and faults.

8. The lesser tectonic forces directed northeastward from the Forest City basin in the nearsurface rocks, as suggested by the structural relations, might be expected to open locally some of the shear joints by tensional action. Many of the northwest-striking shear joints are more open and more commonly contain vertical lead veins than the northeast-striking shear joint, which are, in many places, tight and unmineralized. The tightness of the northeast-striking shear joints suggests that they acted as the main shear direction for both the greater north- and the lesser northeast-directed tectonic forces. In contrast, the northwest-striking

joints that were formed by the north forces were opened by tension resulting from the northeastward-acting lesser force.

9. The most common strike of shear faults is northwest, the same general direction as the northwest shear joints.

The inclined joints seem to be shear and tension fractures that are related to the local folds, and many are directly related to the reverse faults. They may well be incipient fractures that, where further developed, became reverse faults and more rarely normal faults, as was actually observed in all stages in the Dodgeville mine, Dodgeville, Wis. Characteristically, the inclined joints form zones that are similar to the reverse fault zones on the flanks of folds, and likewise many of them dip toward the anticlinal areas. Like those of the faults, the strikes of the inclined joints follow closely the trends of the fold axes and swing around the noses of the folds to form arcuate patterns.

The inclined joints apparently developed during the latter part of the period of folding, after the rocks had passed their elastic limit and consequently were fractured. Shearing occurred because the continued thrust of the regional compressive force was relieved in the vertical plane.

DEVELOPMENT OF THE STRUCTURES CONTROLLING THE ORE BODIES

The suggested mode of development of the tectonic structures that control the main zinc ore bodies is shown in the sequence of five plan views of an idealized syncline in figure 44 and the corresponding five sections across the fold in figure 45. The first plan view and section show a simple sycline, elliptical in outline, typical of smaller synclines in the district. The short length relative to the width is typical of the district folds. This flexure has been developed by major north- and south-directed compressive forces. These forces acted in the form of a series of pulsations, by zigzag bedding-plane slickensides in certain mines. The normal expected axial elongation of the syncline has been prevented by the second or northeast- and southwest-acting forces which were essentially static-holding forces which also at times acted in a series of slight pulsations. That these two directions of force acted during the same general period—sometimes together, sometimes in alternating sequence—is shown by sharply curved and zigzag slickensides observed along bedding-plane faults in the Dodgeville mine (pl. 10; fig. 70).

The second plan view and section (figs. 44 and 45) show a later stage in the progressive development

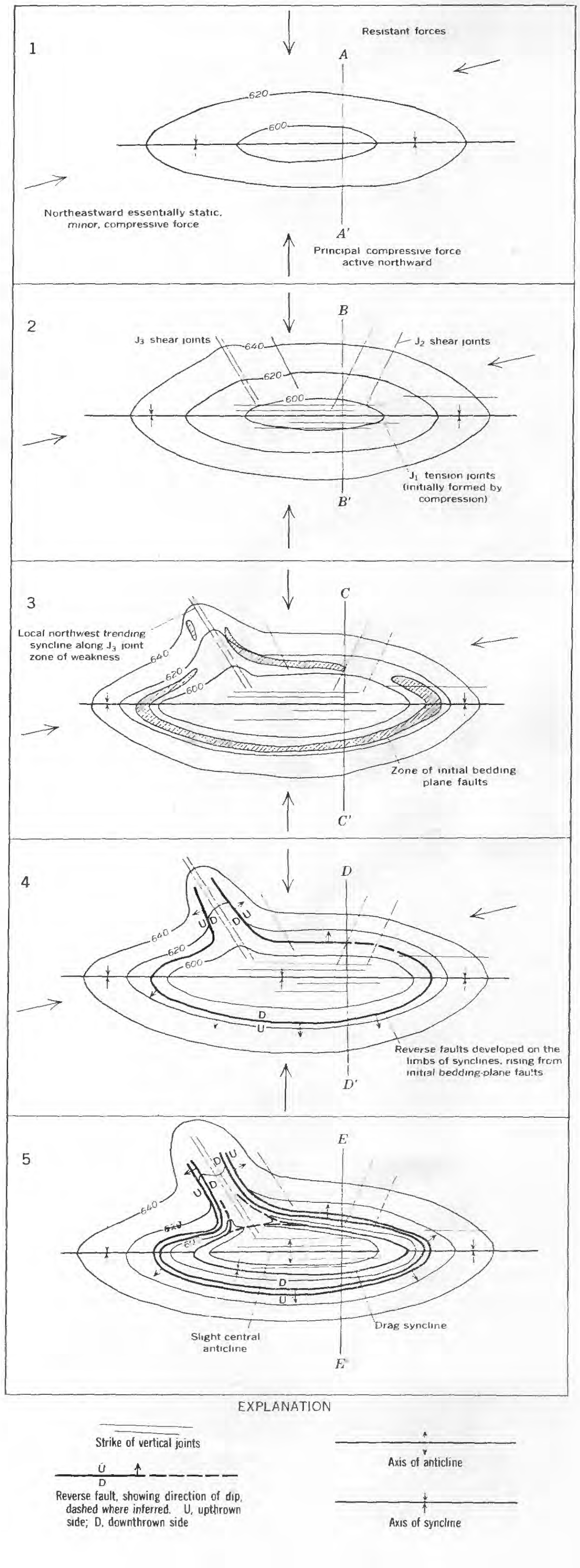


FIGURE 44.—A series of five diagrams illustrating the progressive structural mode of development of a typical third-order syncline by lateral compressive forces.

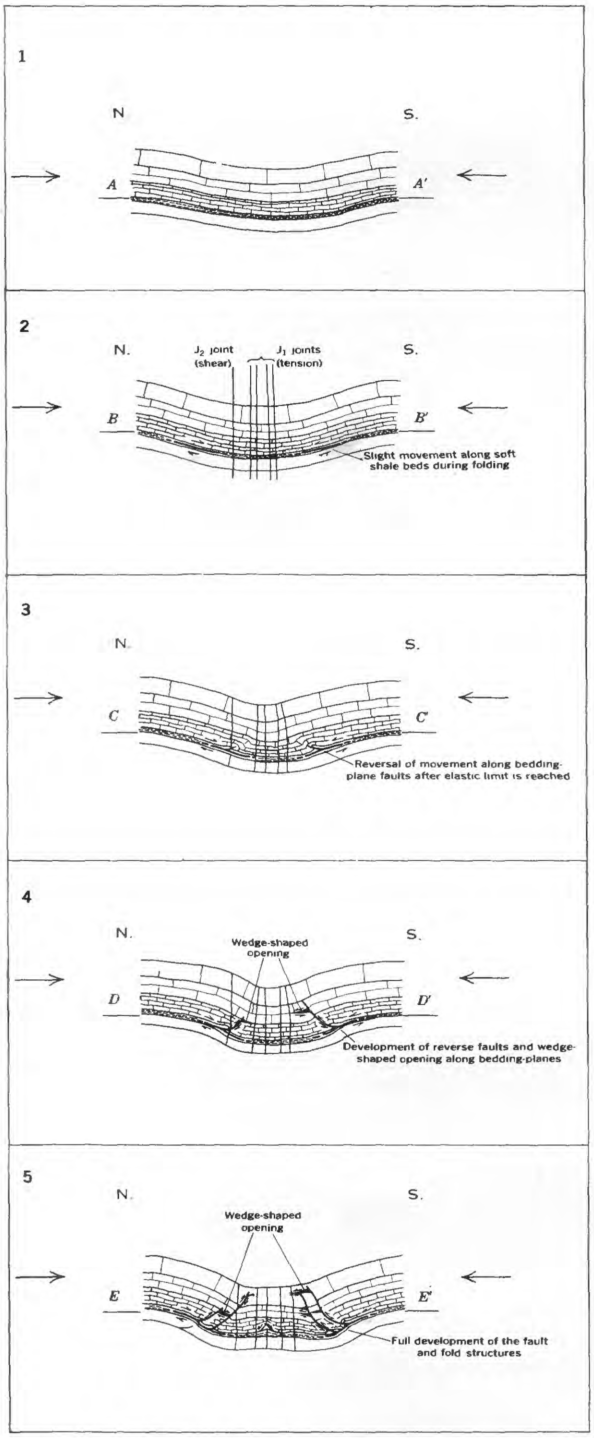


FIGURE 45.—A series of five diagrammatic sections across the third-order fold shown in figure 44 illustrates the progressive development of the folds and faults by the suggested action of lateral compressive forces.

of the structure. The width of the fold has decreased, its amplitude has increased, and related joints have developed. Vertical J_1 joints have formed parallel to and along the fold axis, and northeast J_2 and northwest J_3 shear joints have developed to form a shear pair whose acute angle is bisected by the line normal to the fold axes. As shown in the section, bedding-plane movement has begun along the plastic, incompetent shale layers of the Spechts Ferry member so that the overlying beds have moved updip toward the anticlinal axes.

The third plan view and section (figs. 44 and 45) illustrate the structure just after the elastic limit of the beds being deformed under the light cover has been reached. Previous to this period the deformation was transmitted through both the competent and underlying incompetent beds. With the already developed slight flexing, the compressive forces acted at a slight angle to the folded beds, and no longer parallel to them. Because of the light cover these underlying incompetent beds reached their elastic limits at a very early stage in the folding, but the compressive forces continued to be transmitted in the overlying competent dolomites. As a result of the early attainment of the elastic limit in the incompetent beds, a reversal of movement took place along the bedding planes in these strata. The deformation now changed, because the transmittal of the forces was restricted to the competent beds, which tended to force the rock masses overlying the anticlinal areas up and over the synclinal areas, using the incompetent layers as glide planes. Because these incipient bedding-plane faults or glide planes in the incompetent beds were developed at a slight angle to the active lateral forces, and the beds had reached the elastic limit, the movement tended to cut across the beds and form initial fractures slightly inclined to the beds and across them. This action started the formation of the inclined fractures from the original bedding-plane faults.

In figures 44 and 45, the third plan view and section, a northwest-trending minor syncline is partly developed; and it is localized by a zone of weakness along a pair of master J_3 shear joints. This subsidiary syncline is the result of the prevention of elongation of the beds in an east or west direction by the resisting forces in the northeast and southwest directions, plus minor active pulsations of this force. On the flanks of both synclines, owing to the combined action of the two compressive forces, bedding-plane faults have been formed along the plastic, incompetent shale of the Spechts Ferry Member. As the elastic limit has been reached in these incompetent layers, the deformation now changes to a movement of the rock masses of the anticlinal areas toward and upon the synclinal area. Small drag folds and crumples are formed in the Spechts Ferry shale member by this shortening movement. The pressure of these shale crumples aids in the formation of incipient inclined shear fractures in the overlying brittle beds above the crumples. By further compression, owing to the interaction of the two compressive forces, these fractures develop into incipient thrust faults which dip toward the anticlinal areas, and further shortening results. In the least-deformed north part of the district—for example, in the vicinity of Dodgeville, Wis.—the deformation never advanced beyond this stage, and it is still observable in the mines of this part of the district.

Plan view no. 4 and the corresponding section (figs. 44 and 45) illustrate the continued development of the structure. The compression and resultant shortening have continued, and thrust fractures have developed upward at an increasing angle of dip as the more competent overlying beds are transected. The maximum angle of dip reached by the thrust planes is 60° in the most competent beds but is generally about 45°. The movement of the anticlinal blocks toward the intervening synclinal areas is thus deflected upward along these thrust planes. Marked reverse-fault drag is produced in the beds that border the faults, but principally in the lower incompetent beds. When the rising fracture reaches a prominent incipiently-open bedding plane beneath a particularly competent bed, the movement is diverted nearly horizontally along the bedding plane into the footwall area. The deflected movement is an inward thrust of the overlying beds toward the syncline, combined with a vertical lifting of the overlying bed by the upward force component that lifted the hanging wall of the reverse fault. This local opening of the bedding planes is greatest directly above the initial reverse fault, and by a hinge movement of the overlying beds decreases in the footwall area to form a wedge-shaped opening. When vertical relief of pressure became greater than the horizontal relief of pressure, the inclined fracture again began to form upward, either directly above the initial fault or stepped inward at distances of 5 to 20 feet in the footwall block. Numerous structures in the moderately deformed central part of the district exhibit this stage of structural development as shown in the Trego mine, figure 30.

The last plan view and accompanying section (nos. 5 and 5a, figs. 44 and 45) illustrate the maximum stage of the structural development, which the most highly deformed part, is typical of the southern part of the district, and in a few local areas farther north (Hoskins mine, fig. 41). The reverse faults have cut higher into the overlying beds by the continuation of the previous mode of fault development. Apparently by this process, nearly continuous reverse faults were formed obliquely upward across the beds, and these faults were combined with the bedding-plane fractures to form a steplike combination of the planes of movement. As the formation of the faults continued, inner, or footwall, parallel reverse faults were developed down from each of the steps and up from the clay bed, to form a shear zone of bedding-plane faults and reverse faults that show a rhomic pattern in cross section. As the rocks of the hanging wall continued to rise, the planes of the inclined faults were smoothed by friction of the walls into more even slickensided surfaces. A prominent drag syncline is usually formed in the footwall of the reverse fault zone. The formation of the drag synclines tended to warp the original central axial synclinal area into a very low slight anticlinal ridge parallel to the axis of the general synclinal structure. Along this central axis are found the J_1 tensional joints, which are locally further opened owing to the additional deformation. The entire structure is now a small ramp-type graben (Willis, 1928, p. 491–502), with inward thrusting of the overlying beds from the surrounding sides riding up and over the central synclinal area. In the central area between the two opposing flanking fault zones the incompetent beds of the Decorah formation locally are arched up into small parallel anticlines generally along and beneath a vertical tension joint that forms a zone of weakness parallel to the length of the main syncline. Small horsts bounded by outward-dipping normal faults are formed by the local upward bulges of the incompetent beds, as is illustrated in the center of the cross section 5a (fig. 45), and also in the cross sections of the Graham-Ginte mine (fig. 43).

Simple compressional cross-folding apparently is the main origin of the district structures, but though the evidence is less clear, the compressional forces in many places combined into force couples which aided in the production of the vertical shear faults, basins and domes, and oval pitch- and flat-type fault structures. Force couples must have been locally notable factors in producing the structures in those areas where the major folds bend sharply such as near Mifflin, and Meekers Grove, Wis.

The main fractures that form these fault zones were well developed prior to mineralization, and evidently a lapse of time took place between their main period of formation and the introduction of the mineralizing solutions. However, minor overlap of the two processes occurred inasmuch as deformation continued at intervals during the deposition of the ores. The deformation ceased near the end of ore deposition or shortly thereafter. The displacement of bedding-plane and reverse-fault zones by shear faults that bear unsheared ore—as in the Liberty mine—indicates that the reverse-fault zones were essentially developed prior to shear faulting. Inasmuch as the shear faults are thus premineralization, the existence of the reverse-fault zones—themselves of still earlier age—is fully established as antedating mineralization. The later tectonic movements appear to have accentuated the earlier structures. Solution of the calcareous beds in the incompetent Decorah formation during ore deposition greatly aided this process.

Solution of the adjacent rocks has been an important and characteristic feature of the mineralized fracture zones, particularly in the limestone strata. The ore-bearing solutions penetrated the main fractures and accompanying breccia zones and dissolved the calcareous wall rocks. In places the solutions dissolved the rocks of both walls, in other places only the rocks of one fracture wall. Although they are much less affected than the limestones, the more calcareous parts of the dolomites have been partly dissolved to form a porous spongy rock full of small irregular solution tubes and cavities. Solution apparently occurred near the end of the general deformation period, when it accompanied the deposition of the ores. Pulsations of the compressive forces combined with some differential compaction apparently closed many of the openings that were formed in the limestones during the mineralization and solution period. The shaly residues of the dissolved limestones were deformed by the compressive pulsations with resultant tight local folding, shearing, and plastic flowage in the affected beds (fig. 38). This solution seems to have aided the tectonic forces by providing space so that these forces could continue to act. The solution thinning of the limestone beds near the base of the fracture zones has locally produced a few feet of gentle slumpage of the overlying dolomite beds. This slumpage, in turn, has relaxed and opened parts of the fractures already formed within them. Solution caves, tumbled breccias and other structures attributable to simple solution and slump, though common in places, are much less common than might be expected in areas where most of the structures were formed by simple solution and collapse.

COMPARISON WITH OTHER VIEWPOINTS REGARDING THE ORIGIN OF STRUCTURES WITHIN THE DISTRICT

It is the writers' tentative conclusion that most of the structural features in the Upper Mississippi Valley zinc-lead district have been produced by regional tectonic compression, a view which seems well supported by the available field evidence. This evidence also points to some accentuation of the minor structures by solution of the calcareous beds, which is in agreement with the views of many men who had previously studied the district. The writers' study has added new data that emphasize a close genetic interrelationship between most of the observed structural features. In certain instances the views of the writers are at variance with older views, and even with some contemporary interpretations. Much remains to be determined about the structure of this area, and some of the viewpoints here expressed may require modifications after later studies.

A discussion of the ideas as to the origin of these structural features will be given in the following paragraphs. The references for the viewpoints of the men cited are listed in the annotated bibliography in this section of the report.

All the geologists who have studied the district have recognized the presence of broad open folds of considerable magnitude, attributed by most of them to tectonic compression.

The view of the writers that the lesser folds are also the result of lateral compression concurs with the views of Percival, Calvin, W. H. Emmons, Scott, and Behre. In opposition to these views are those expressed—by Whitney, T. C. Chamberlin, Bain, Grant, Cox, Shaw and Trowbridge, and C. K. Leith—that they were formed as a result of a combination of original irregularities of deposition, and slumping by differential compaction, plus some lateral compression acting on these original irregularities. A third view, advocated by Blake and recently by Willman, suggests that these folds were partly formed by lateral compression followed by major slumping in the synclines owing to the thinning by solution of the calcareous beds in these areas.

The larger faults, the presence of which is now well established, were recognized by only Percival and Jenney. The other geologists either did not mention or observe major faults or else claimed that they did not exist.

The existence of smaller faults was noted by Blake, Spurr, W. H. Emmons, Andrew Leith and Lund, C. K. Leith, Scott, Behre, and Willman. Like the present writers, Emmons, Spurr, Scott, and Behre described these faults as compressional features, whereas the others considered them a result of collapse following either solution of the calcareous beds or differential compaction. The other geologists described the fractures but considered them to be essentially joints of no measurable displacement.

Solution thinning followed by collapse of the beds overlying the dissolved areas were considered by Blake and recently by Willman as the deformational actions that produced the reverse and bedding-plane faults. The views of Cox are in essential agreement with these conclusions. On the other hand, the present writers suggest that although solution is a prominent feature of certain of the ore deposits, its main result was to open the fractures and to accentuate the folds by minor slumping in these deposits. Only locally was solution a cause in itself of minor folding by slumping, brecciation, and fracturing.

The joints are attributed to a variety of origins by the geologists who studied the district. The earliest view was that of Percival, who related the joints to regional deformation. Whitney, in contrast, suggested that the joints were shrinkage cracks that resulted from the consolidation and compaction of the sediments shortly after their deposition. Jenney concluded that they were actually shear faults, in places of large lateral displacement, and that individual fractures cut through all the sedimentary rocks to the basement. Spurr suggested that they were tensional fractures formed by the subsidence and contraction of the beds after uplift and heating of the rocks by underlying buried magmatic intrusions. Most of the other geologists recognized essential differences between the more open "east-west" (J_1) joints and the tighter "north-south" (J_2, J_3) joints. However, the hypothesis proposed by them was that the joints were tensional fractures opened along the fold axes during the period of regional compression. The writers concur in part with this view but restrict this origin to the more open "east-west" (J_1) joints, which were originally formed as compression joints by the regional compressive force. The tighter, northeast (J_2) and northwest (J_3) joints are considered to consist of a shear pair whose acute angle is bisected by the lateral compressive forces acting generally in a north or south direction.

ORE DEPOSITS

The ore deposits of the upper Mississippi Valley district are distributed over a wide area (pl. 1) in Wisconsin, Illinois, and Iowa. Lead and zinc ores [15] have been the principal metallic ores mined, but small tonnages of high-grade copper ores and barite have been produced. Iron sulfides have been mined both separately and as a byproduct of zinc mining for the manufacture of sulfuric acid. Limonite and hematite have been mined in the Iowa and Wisconsin parts of the district for iron ore. The waste rock, both from the mines and the jig mills, has been widely used for road metal and railroad ballast.

[15] The term "ore," as used in this report and in its illustrations to refer to the 20th century product of the zinc-lead mines, is defined as run-of-mine ore (not concentrates) that averages 3 percent or better combined metallic zinc and (or) lead. Where "ore" is described in mines, ore bodies, or shown on the illustrations, the extra factor of a mineable thickness of a minimum of 6 feet is included, so that all ore shown or described is equal to a six-foot thick zone of ore and rock that averages 3 percent or better zinc and (or) lead. Any mineralized rock leaner than this is not included. During the 19th century "ore" commonly meant high-grade hand-sorted concentrates that averaged 80 percent lead ("lead ore"), 30 to 60 percent zinc ("zinc ore"), 30 to 50 percent zinc in zinc carbonate ("oxidized zinc ore"), or 10 to 30 percent copper ("copper ore").

HISTORY OF MINING

The upper Mississippi Valley district is one of the oldest known mining areas in the United States. M. Jean Nicolet traveled up the Mississippi River in 1634 and passed the area of the mines, but no record remains whether he noted the presence of lead in the area (Thwaites, 1895, p. 272). The first recorded indication that lead was known in the area was in 1658–59 when Raddison and Groseillers "heard of lead mines among the Boeuf Sioux, apparently in the vicinity of Dubuque, Iowa" (Thwaites, 1895, p. 272). The next notation was on Hennepin's map of 1687, which shows lead mines in the vicinity of the present town of Galena, Ill. (Thwaites, 1895, p. 272). About 1690 Nicholas Perrot established a temporary trading post for lead opposite the present site of Dubuque, Iowa (Bain, 1906, p. 2). Perrot was considered as the actual discoverer of the lead deposits by the French of this period, and his trading post probably marked the beginning of actual mining by the French and the Indians, who soon learned the value of lead ores.

LeSueur in 1699 made the first mining exploration of importance in the area. LeSueur (Thwaites, 1895, p. 275–276)—

> set out from France in 1699, in D'Iberville's second expedition to Louisiana, which arrived at its destination in December (1699). He had been commissioned by the king to explore and work "the mines at the source of the Mississippi," and had 30 miners assigned to him. His reporter and companion Penicant, after speaking of the rapids in the Mississippi at Rock Island, says: "We found both on the right and left bank the lead mines, called to this day the mines of Nicholas Perrot, the name of the discoverer. Twenty leagues (39 miles) from there on the right, was found the mouth of a large river the Ouisconsin." It was the 13th of August 1700, when they arrived opposite Fever River, which Penicant calls "Riviere a la Mine." He reports that up this little river, a league and a half, there was "a lead mine in the prairie." They passed up the Mississippi, Penicant mentioning two streams which correspond to the Platte and Grant Rivers, in Wisconsin, and says that LeSueur "took notice of a lead mine at which he supplied himself,"—supposed to be what afterwards came to be known as "Snake Diggings," near [at] Potosi, Wisconsin.

In 1743 M. Le Guis noted that 18 or 20 miners were operating in the Fever River (now known in Illinois as the Galena River) region; they mined during the better seasons of the year and moved south during the winter (Thwaites, 1895, p. 276–277). Later, in 1766, it was recorded that lead was shipped by the French twice a year from the west side of the Mississippi River in 20-ton boats. The same year Jonathan Carver, who traveled down the Wisconsin River from Portage to Prairie du Chien, Wis., visited lead mines at Blue Mounds and reported that lead was abundant in the vicinity of the mounds (Durrie, 1872, p. 225). These incomplete records suggest that probably the French and Indians were mining lead ore on a small scale during all of the 18th century and that several deposits later became important mines.

The first serious attempt made by white men to settle in the region to mine lead ore was by Julien Dubuque. According to Schoolcraft (1821, p. 348), the discovery of lead in Iowa was made by the Indians, as he states in the following paragraph:

In 1780 a discovery of lead ore was made upon their lands by the wife of Peosta, a warrior of the Kettle Chief's village, and extensive mines have since been discovered. These were granted by the Indians to Julien Dubuque at a council held at Prairie du Chien in 1788, by virtue of which he settled on the lands, erected buildings and furnaces, and continued to work the mines until the year 1810. In the meantime (1796) he received a confirmation of the Indian grant from the Baron de Carondelet, governor of Louisiana, in which they were designated the "Mines of Spain."

Dubuque's principal mines were in the vicinity of the present location of Dubuque, Iowa, also along Tete du Morte Creek, about 12 miles south of Dubuque, and at Durango, Iowa, about 6 miles northwest of Dubuque. His house and one of his furnaces were near the mouth of Catfish Creek in Kettle Chief's village. Dubuque apparently employed many of his Indian friends in his mining and prospecting, although he sometimes sent Canadians and halfbreeds to check discoveries and to establish claims. His men brought the lead to his large trading house, and in this manner the entire region of lead mines in Iowa, Wisconsin, and Illinois became familiar to Dubuque's men before any permanent American settlement (Thwaites, 1895, p. 282–283).

One of the results of Lieutenant Zebulon Pike's expedition up the Mississippi River in 1805 was a visit with Dubuque. He found M. Dubuque "polite but evasive" and he was prevented from seeing the mines, but they signed a joint statement declaring that 20,000 to 40,000 pounds of lead were recovered per year, the yield being 75 percent of the ore smelted. (Pike, 1810, p. 10–11, Appendix to pt. 1, p. 3–5).

Mining continued until Dubuque's death in 1810, after which the Indians destroyed his home and trading post. They continued to mine ore and trade it with the French and Americans until after 1820. In 1810 about 400,000 pounds of lead were sold by the Indians to traders at Prairie du Chien (Thwaites, R. G., 1895, p. 285) and probably other lead was shipped down the Mississippi. Gradually a number of other lead deposits were found. One of these deposits, the Buck Lead (1 mile north of Galena), was being mined at least as early as 1810 (Meeker, 1872, p. 281). By 1820 lead deposits had also been found near Elizabeth, Ill. west of Bellevue, Iowa; at the Vinegar Hill Diggings north of Galena, Ill.; at Fairplay, Potosi, Blue Mounds, and perhaps Beetown, Wis. (Forsyth, 1872, p. 194–195.)

In 1819 the permanent settlement of the area by United States citizens began with the arrival of Jesse W. Shull, under military protection, to Gratiot's Grove just south of Shullsburg, Wis. (Bain, 1906, p. 3). On July 5, 1822, Colonel James Johnson and others, supported by troops, arrived on the Fever (now Galena) River and joined the 500 Indians who were already mining there (Meeker, 1872, p. 272). Johnson and his associates settled at Galena, Ill., and began mining on a considerable scale. He bought the Buck Lead from "Old Buck" the Indian for $300 and also bought the Cave Lead near the Vinegar Hill Diggings. He was followed by many new settlers, including Moses Meeker, in 1823, and Major Roundtree. The towns of Hazel Green and New Diggings, Wis., were settled in 1824, after rich discoveries of lead were made there. Except during the Black Hawk war in 1832, the settlement and development of the area proceeded very rapidly, and most of the important lead areas were found by 1830 (Meeker, 1872, p. 271–296).

By an act of Congress in 1807 (Laws, 1807, p. 127) the government acquired ownership of the mineral lands of the upper Mississippi Valley district and the Territory of Missouri. The Land Office was given control of these mineral lands, which were reserved from sale with provision that they should be leased by the government at an annual rental. In northern Illinois the reserved holdings amounted to more than 340,000 acres, in Iowa to 180,000 acres, and in Wisconsin to more than 1,420,000 acres. A superintendent of mines was employed, and a royalty was exacted of one-sixth to one-tenth, payable in cash or lead. This leasing system was tried with increasingly poor success until 1846, when a decision was made to sell the land. Most of the leases had been given in northwestern Illinois and Wisconsin, but in Iowa, where the system was strongly opposed by the local courts, only a few leases were granted.

The United States Government took over the Dubuque claims and Iowa remained Indian Territory until 1833. Thus the permanent settlement of Iowa was prevented until 1833, although lead is known to have been shipped in 1822 (Meeker, 1872, p. 272) and attempts to settle Iowa were made in 1830 and again during the Black Hawk War in 1832.

As a result of the rapid settlement of the upper Mississippi Valley district—the population rose from 200 in 1825 to 10,000 in 1828 (Chandler, 1829)—and the discovery of numerous lead deposits, the production of metallic lead increased rapidly from 168 short tons during the period 1821 to September 1823 to 6,672 short tons in 1829 (Bomford, 1829, p. 128). After a drop during the unrest of the Black Hawk War, the production increased to a peak of 27,134 short tons in 1847 (Winslow, 1894, p. 147). From about 1830 to 1871 the district was by far the most important lead producing area in the United States, exceeding even Missouri. Plate 9 is a reproduction of a map made in 1829 during the earliest American settlement of that part of the upper Mississippi Valley district east of the Mississippi River. This map shows the rapid rate of discovery of lead deposits within the district a very few years after its first permanent settlement in 1822, and the fact that the first main influx of settlers into Wisconsin was by the prospectors and miners engaged in lead mining. It was not until after 1850 that other parts of Wisconsin became equally populous and important, and farming became the principal occupation.

As the Mississippi River was the main artery of transportation in the first half of the nineteenth century, the river ports of Dubuque, in Iowa, Galena and Dunlieth (now East Dubuque), in Illinois, and Potosi Cassville, and the former town of Helena, in Wisconsin, grew quickly and thrived. The first steamboat arrived at Galena in 1822, and regular traffic was established in 1827. Ninety-nine steamboats arrived at Galena in 1828, and in addition 14 keel boats landed there (Chandler, 1829). The decade from 1840 to 1850 marked the greatest era of river traffic, with 300 to 400 boats arriving every year. The importance of river transportation diminished when the Galena & Chicago Union Railroad was built from Chicago to Freeport, Ill., in 1852 and finally ceased when the Illinois Central Railroad connected Freeport with Galena in 1855 (Trowbridge and Shaw, 1916, p. 218–219).

The lead was smelted locally, and small lead furnaces were erected in many parts of the district (fig. 46). The primitive furnaces first erected by the French, Indians, and American settlers consisted of simple stone platforms about 15 feet square, upon which wood and ore were placed alternately and burned. Wood was added as needed, and lead was drawn off from the central well in a small trough and collected as a rough bowl-shaped 70-pound pig in a stone basin. The slag from the first smelting was reburned in a similar smaller furnace until most of the remaining lead was recovered (Calvin and Bain, 1900, p. 486). This process was so very wasteful that in the 1820's a cupola furnace was introduced, which recoverd between 65 and 75 percent of the metal in the ores. This recovery was soon improved by the use of the Scotch hearth—probably the first in the United States was erected in 1835 about midway between Mineral Point, Wis., and Dubuque, Iowa (fig. 46) (Calvin and Bain, 1900, p. 594), probably at

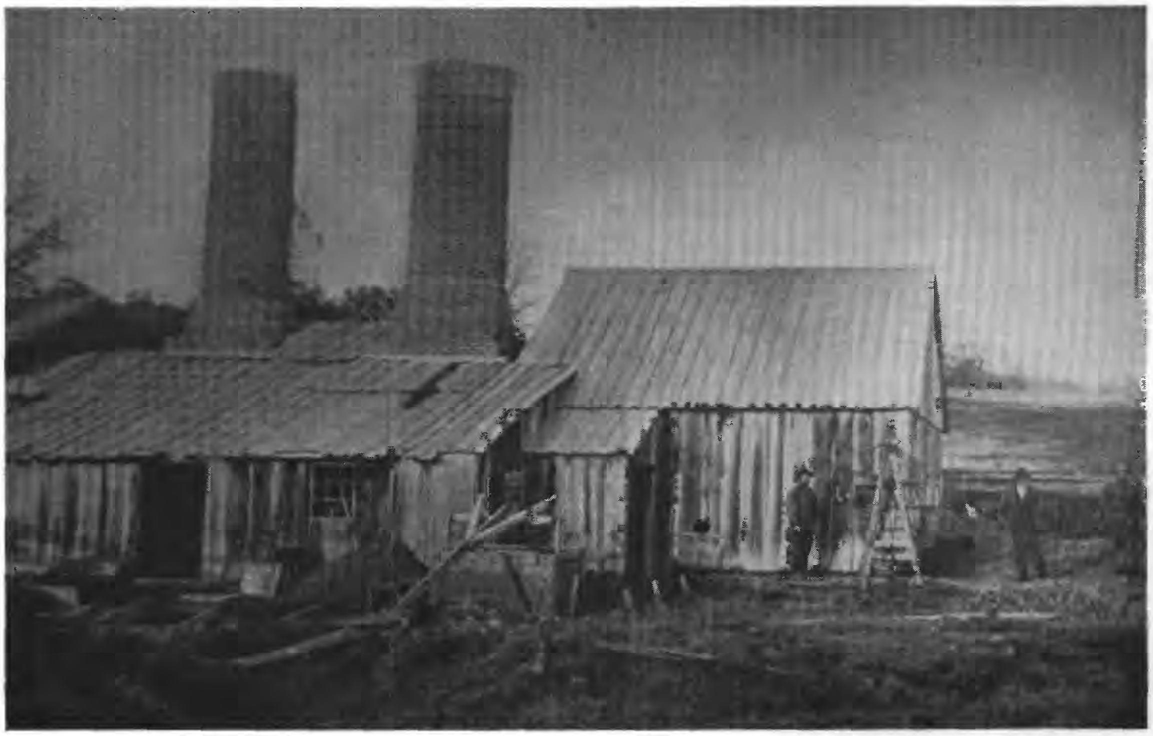


FIGURE 46.—Early lead furnace. The Straw & Co. lead furnace was of the Scotch hearth type and possibly was the first of this type built in the United States. According to the daughter of the owner, it was built in 1838 rather than 1835, but otherwise the furnace fits the description of the one mentioned by Calvin and Bain (1900, p. 594). Lead ores from the Platteville area were smelted in the furnace until 1892. The site of the furnace is at the south edge of Platteville, Wis. Photograph courtesy of the Wisconsin Institute of Technology.

Platteville, Wis. Lists of many important furnaces, as well as information on some of their capacities, construction, and production can be obtained from some of the early reports (Calvin and Bain, 1900, p. 593–597; Strong, Moses, 1877, p. 742–750; Cox, G. H., 1914, p. 14–15). Some of the furnaces continued in operation until the beginning of the present century. Evidence of the industry may still be seen in ruins and old slag piles in many parts of the district; the hearth of a Scotch-type furnace remains at Dodgeville, Wis.

Most of the lead was shipped out in bulk form, but lead-pipe and sheet-metal factories were established in Galena, Ill. Two lead-shot towers were built, one at Dubuque, Iowa (fig. 47), and the other, a round shaft in solid rock over a spring in a cliff along the Wisconsin River, at the former town of Helena, Wis. Both of these towers are still in a fair state of preservation. Most of the bullets used in the United States from 1820 to 1860 were made of the lead from the district, and the metal was also used as currency by the Indians, trappers, and fur traders in the area.

FIGURE 47.—Lead-shot tower at Dubuque, Iowa. This tower was operated in the middle part of the 19th century. The frame upper part of the tower has been removed. The molten lead was dropped through a sieve into a water tank below, and during its fall the lead drops assumed the necessary spherical shape, which they retained upon chilling in the tank.

A general land survey of the area was made in 1834, establishing the townships, ranges, and sections. Dr. David Dale Owen was selected by the Commissioner of the General Land Office to take charge of the "United States Geological Survey of the Lead Region." The party consisted of Dr. Owen, Dr. John Locke, and 139 assistants. The field work, which consisted mainly of locating and mapping the lead mines of the entire district, was begun in September 1839 and completed in November of the same year. A report was published without the plates and maps in 1840 (Owen, 1840, 161 p.), and a later complete report was printed in 1844 (Owen, 1844). This survey was perhaps the first important geological study made by the United States Government in the entire country.

The decline of lead mining began in 1848. The main causes were the depletion of the easily found, superficial lead deposits in this area and the discovery of gold in California. Lead production decreased, at first rapidly and then slowly, until at the present time it has nearly ceased except as a byproduct of zinc mining.

Zinc ores in the district were first noted by Owen (1840, p. 41–42) in 1839, but owing to a lack of market for the ores and the difficulty in smelting, they were not recovered until 20 years later. The first zinc ore, which was in the form of zinc carbonate, was obtained from mine dumps. Two zinc smelters were erected between 1852 and 1860 (Hall and Whitney, 1862, p. 371–373), one at LaSalle, Ill., by Messrs. Matthiessen and Hegeler and the other at Mineral Point, Wis., by Mr. Robert George. Matthiessen and Hegeler commenced operations in 1852, experimenting with ore from the upper Mississippi Valley district (Calvin and Bain, 1901, p. 591). This operation accomplished the successful smelting of ores in 1860, and the company has continued in production until the present time.

In 1859 a furnace designed after the Belgian model was constructed by Mr. George at Mineral Point to process the ore obtained from adjacent mines. It had a capacity of 200 pounds per day. The entire quantity of metal produced did not exceed 2 or 3 tons, and the furnace was abandoned in a short time. A second attempt at smelting zinc ores at Mineral Point was started in 1866 by Mr. George and the Jones brothers who shipped spelter in some quantity until 1869. In 1867 they erected a zinc oxide furnace which produced until 1871. This plant was torn down in 1877 and sold for scrap (Strong, 1877, p. 743). About 1882 these men erected a third plant, this time only a zinc oxide furnace, which, after an uncertain existence for some years, was bought by the New Jersey Zinc Co. and operated successfully until dismantled in 1931.

Zinc mining increased as the lead mining decreased in the latter part of the 19th century. From 1860 to 1873 the production of smithsonite exceeded that of sphalerite, but after 1873 the annual production of sphalerite was always greater than that of smithsonite. The production of zinc carbonate continued in diminishing quantities until 1931, when the Mineral Point oxide plant was closed. The first sphalerite shipped from the district came from the Rooney, Swift and Co.'s mine in 1867 (Dugdale, 1900, p. 34). Zinc production increased so rapidly for the first 20 years that in 1873, 10,236 tons of about 60 percent zinc sulfide concentrates and 6,084 tons of zinc carbonate concentrates were shipped from the following localities in the district: Marsden Black Jack mine, 3 miles south of Galena, Ill.; Buncombe, Leadmine, Shullsburg, Meekers Grove, Platteville, Beetown, Mineral Point, Mifflin, Linden, Dodgeville, Centreville, Highland, and at the Crow Branch Diggings near Livingston, all in Wisconsin (Chamberlain, 1881, p. 365–571).

Copper was mined in the district intermittently from 1837 to about 1909. Most of the mining was restricted to a small area west of Mineral Point, Wis., but small tonnages have also been mined northwest and east of Gratiot, near Linden, at Highland, and north of the Wisconsin River near Wauzeka and Mount Sterling, Wis. Much of the copper was smelted locally at three small furnaces near Mineral Point, operated by William Kendalls and Co., Charles Bracken, and Curtis Beach. Most of the copper mining had ceased by 1850, but other attempts were made in 1860, from 1873 to 1880, and, last of all, northwest of Gratiot, in 1909. None of these later attempts was profitable although considerable work and money were expended. Probably a total of about 10,000 tons of 10- to 20-percent copper ore was mined at all of these properties.

In the 1890's a roaster and magnetic separator were invented by a Mr. Blake to separate the iron sulfides from the high sulfide zinc ores, and in 1899 one of the first contact sulfuric acid plants, using the Schroeder-Grillo process, was erected at Mineral Point to manufacture sulfuric acid from the iron sulfides as a byproduct of the zinc oxide plant previously established there.

Forty-five zinc mines were producing ore in the district in 1900, but many were small. About this time the zinc deposits of the district were actively promoted and developed by local interests, and for a period of about 10 years the district mushroomed with numerous development companies. Many of these companies were formed purely as stock-selling ventures, whereas others were serious attempts at prospecting and mining.

Steam mills of the type used in the Joplin, Mo., district were introduced for the concentration of ore about 1900. These power-driven gravity mills, for the most part, replaced the expensive, wasteful hand-jigging and hand-dressing methods formerly used in the district. The mills usually consisted of a primary crushing unit plus 7-cell, wooden, Harz-type jigs which ranged in number from 1 to 3 banks. A 50-ton mill had 3 banks of jigs, all steam driven. In several of the mills concentrating tables were used to re-treat the tailings (Bain, 1906, p. 146). This method produced concentrates that ranged in grade from 25 percent zinc to a maximum of about 60 percent. The iron sulfide content in the jig concentrates was commonly so great that roasting and magnetic concentration were necessary to purify the concentrates to prevent penalties by the smelters.

About 1906, mining men of Wisconsin, particularly at Platteville, realized the need for technically trained men to assist them in mining and milling. In order to obtain trained surveyors, assayers, mine supervisors, and mill men, they succeeded by an act of the Wisconsin State Legislature in establishing the Wisconsin Mining Trade School at Platteville, Wis., in 1907 (Dugdale, R. I., and Melcher, M. A., oral communications, Nov., 1949). This school, now called the Wisconsin Institute of Technology, with an annual enrollment of about 300 students, still provides trained personnel for the mines of this district and other areas.

During the period from 1908 until about 1917 mining activity continued to grow in size and efficiency. Four larger companies were producing most of the ore at the close of World War I: the Vinegar Hill Mining Co.; the Mineral Point Zinc Co., a subsidiary of the New Jersey Zinc Co.; the Wisconsin Zinc Co., a subsidiary of the American Zinc Co.; and the Frontier Mining Co. Modern methods of mining were introduced by these companies, particularly the Vinegar Hill Mining Co., which introduced power shovels, battery locomotives and cars, and cage hoists and thus reduced mining costs. Production in the district rose steadily to an all-time high in 1917, when 64,000 tons of zinc metal were produced. Rising costs, depletion of known reserves, and the depression of 1920–21 with its sudden drop in zinc prices, resulted in almost a cessation of production, a blow from which the district never fully recovered. Large scale prospecting nearly ceased except by the Vinegar Hill Mining Co. The reserves, which in 1920 were still large, were thus further reduced by additional mining in the 1920's, the rate of which greatly exceeded the discovery of new ore deposits by prospecting.

During the first World War the United States Government erected a sulfuric acid plant and roaster at Cuba City, Wis. This plant was operated for some years by the National Zinc Separating Co. It was bought by the Vinegar Hill Zinc Co., considerably improved and expanded, and continued in operation until the summer of 1948.

Production increased again at a rapid rate after 1920 only to drop swiftly after 1928 with the inception of the major depression of the 1930's.

Except for the oxide plant at Mineral Point, Wis., which continued to operate until 1930, both the Wisconsin Zinc Co. and the Mineral Point Zinc Co. had ceased active mining by 1929.

During the 1930's only the Vinegar Hill Zinc Co. continued active mining, except for the intermittent production of several smaller companies, the most important of which was the Rule Mining Co., later reorganized as the Badger Zinc Co. In 1929 the Badger Zinc Co. built and successfully operated the first flotation mill in the district, at Linden, Wis. This plant was built to lower costs, to eliminate the wasteful roasting and magnetic separation stages of ore concentration, and to remove the large quantities of barite in the ores.

In 1938 the Vinegar Hill Zinc Co., established a custom jig-flotation mill at Cuba City, Wis., in connection with their acid plant and roaster, and until 1947 they milled most of the ore produced in the district. The custom plant eliminated the need for separate mills by some of the smaller mine operators, who were beginning to resume production at this time, and in this way it stimulated their activity. Many small mines were opened, mainly by local interests, and production rose steadily until 1947. The impetus of the Second World War and the resulting establishment, in 1942, of zinc-lead premium prices above the frozen market price, stimulated mining so greatly that from 30 to 40 mines were in operation during the war years. Considerable remilling by flotation of old jig tailings was conducted by several companies during this period.

When the zinc subsidies were abandoned in 1947, followed by a market drop in the base-metal prices, a large number of smaller mines were closed. However, the discovery of several large new ore bodies by a joint prospecting program started in 1942 by the U. S. Geological Survey and the U. S. Bureau of Mines, greatly stimulated the interest in new exploration in the district. The largest discoveries, the Gray and Bautsch ore bodies that together contain more than 2,000,000 tons of ore, were opened in 1945 by the Tri-State Zinc Co. (Lyons, Heyl and Agnew, 1949, p. 106–108). The studies of the U. S. Geological Survey, in cooperation with the Wisconsin Geological and Natural History Survey and the U. S. Bureau of Mines, have continued since the war. The program was changed from prospecting to the development of geologic techniques for locating new ore bodies, and for exploring and developing new parts of the district in order to expand the producing area. A separate similar study was established by the Illinois State Geological Survey in that part of the district. In 1946–47 several companies started major prospecting programs and used some of the new techniques and information developed during these government investigations. These private prospecting programs discovered a number of important ore bodies in new areas and built up the known mineable ore reserves from about 1,000,000 tons in 1942 to more than 10,000,000 tons in 1950. Ore found by exploration and ore removed by mining have been essentially equal during the years 1950 to 1957, so that the district ore reserves in 1957 are still about 10,000,000 tons (T. E. Mullins, U. S. Geol. Survey, oral communications to Heyl, June 1957). By 1950 four of the larger companies, the Tri-State Zinc Co., the Calumet and Hecla Consolidated Copper Co., the Vinegar Hill Zinc Co., and the Eagle Picher Mining & Smelter Co., were engaged in large-scale mining or mine-development work on these ore bodies. The American Zinc Co., purchased the properties of the Vinegar Hill Zinc Co. about 1955, and assumed active operation of their mines, and also contracted with the Piquette Mining Co., of Platteville, Wis., which opened the first large zinc mine near Tennyson in the Potosi subdistrict. The Eagle Picher Mining and Smelting Co. were operating 5 mines in the district including the former Calumet and Hecla property near Shullsburg, which they purchased. The Tri-State Zinc Co., had opened a new mine, the Amelia, in Illinois in addition to the Bautsch mine which had become the largest in the district by 1957. The New Jersey Zinc Exploration Co. was engaged in a major geological and physical exploration program in a large area of the southern half of the Wisconsin part of the district. Several smaller lead and zinc mines were in operation in 1957 in addition to the large ones, and the district was maintaining its status among the leading zinc-lead districts in the country.

PRODUCTION

The Upper Mississippi Valley zinc-lead district has one of the longest records of continuous production in the United States. As far as is known, actual mining began as early as 1690. Very incomplete historical records reveal that primitive lead mining by the Indians and French probably was continuous from 1700 to 1820. Fairly complete production records since 1820 indicate that ore production did not cease at any time up to July 1, 1957.

LEAD PRODUCTION

After the first influx of American settlers to the area in 1819, production of lead ore increased very rapidly

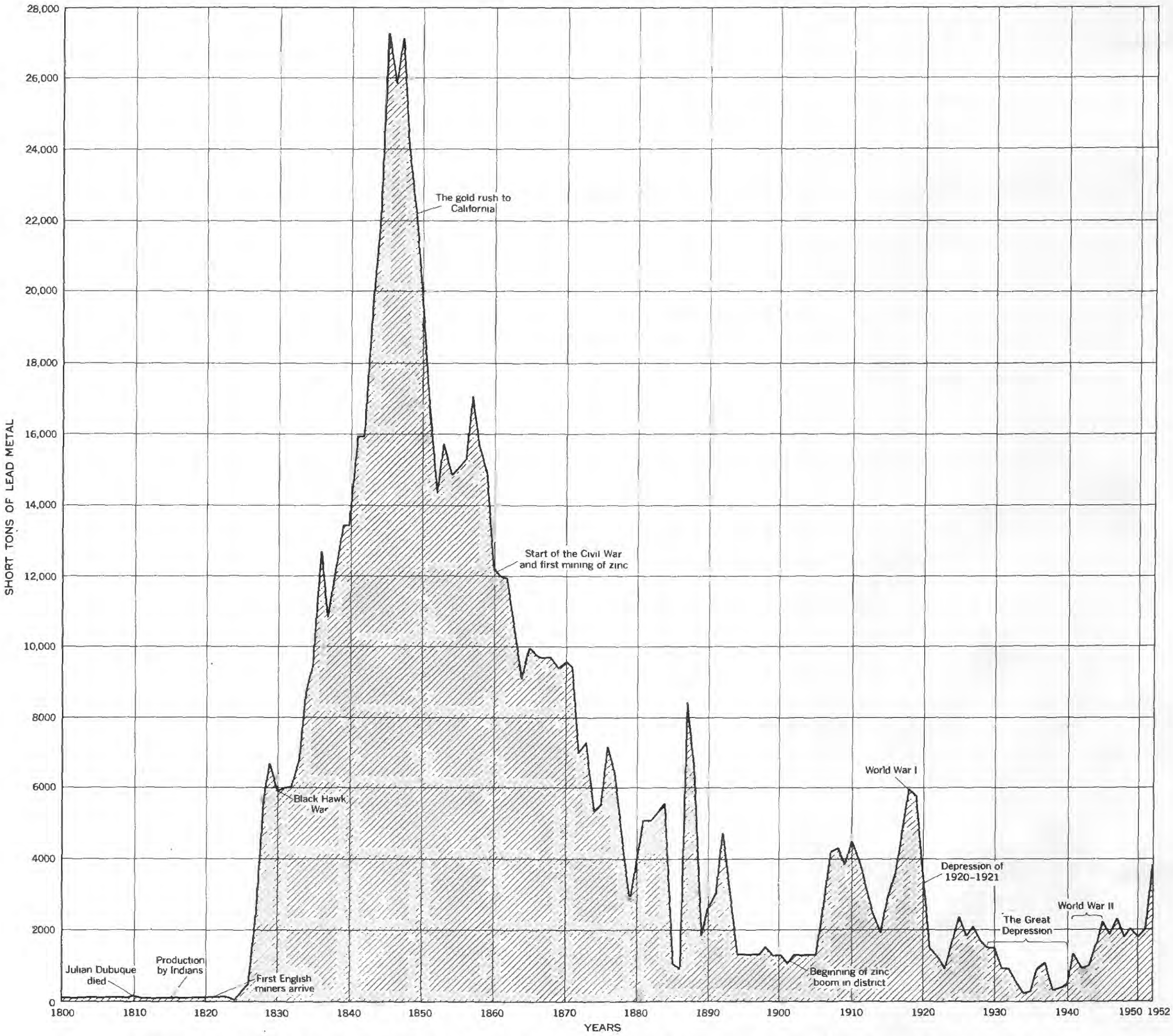


FIGURE 48.—Production of metallic lead, correlated with historical events, upper Mississippi Valley district.

(fig. 48)—so rapidly that by 1830 the district had exceeded Missouri in production. From about 1830 to 1871 the upper Mississippi Valley mining district was by far the most important lead producing area in the United States (Ingalls, 1908, p. 105). The peak lead production was in the years 1845 to 1847 (fig. 48), inclusive, when an average of 26,750 short tons of metallic lead were mined annually (table 1). Production slowly but steadily declined from this maximum until 1938. The production of lead in recent years has increased markedly to nearly 4,000 tons per year in 1953, the largest quantity since 1919. Lead is recovered mainly as a byproduct of zinc mining, and recovery has ranged from 1,000 to 3,688 short tons of metallic lead annually in recent years (table 2A). The total recorded tonnage of metallic lead produced from 1800 to 1953 inclusive, amounts to 830,181 short tons (table 1) that would have a value of $248,000,000 calculated on the basis of 15 cents per pound metallic lead. Quite possibly the actual total production of metallic lead is about 1,000,000 tons, as it is known that a considerable amount of lead was used locally for shot or shipped to other markets than the main ones in St. Louis, Mo., and Chicago, Ill. Slightly more than 50 percent of the lead was mined in Wisconsin and the rest was produced in Illinois and Iowa.

Table 1 shows the recorded production of metallic lead mined and shipped annually from the upper Mississippi Valley district from 1800 to 1954 inclusive. These statistics were compiled from the best available information (see footnotes to table 1), and where accurate figures are not available, prior to 1821, estimates based on scanty recorded data are included. Figure 48 graphically shows the production of metallic lead. The

TABLE 1.—*Metallic-lead production in the upper Mississippi Valley district from 1800 to 1954*

[Footnotes 1-18 give the sources of production data]

Year	Short tons	Year	Short tons	Year	Short tons
1800	[1] 150	1853	[5] 15, 700	1906	[17] 2, 595
1801	150	1854	[6] 14, 827	1907	[18] 4, 202
1802	165	1855	15, 063	1908	4, 363
1803	165	1856	15, 248	1909	3, 818
1804	165	1857	17, 082		
1805	165	1858	[7] 15, 600	1910	4, 534
1806	165	1859	14, 000	1911	4, 038
1807	150			1912	[18] 3, 331
1808	150	1860	[6] 12, 227	1913	2, 519
1809	150	1861	[7] 12, 000	1914	1, 986
		1862	[8] 11, 900	1915	2, 817
1810	200	1863	10, 500	1916	3, 519
1811	150	1864	9, 100	1917	4, 767
1812	150	1865	10, 000	1918	5, 946
1813	150	1866	9, 800	1919	5, 819
1814	150	1867	9, 700		
1815	150	1868	9, 700	1920	3, 435
1816	150	1869	9, 400	1921	1, 506
1817	150			1922	1, 259
1818	150	1870	9, 600	1923	948
1819	150	1871	9, 450	1924	1, 639
		1872	[9] 7, 000	1925	2, 355
1820	150	1873	[10] 7, 336	1926	1, 819
1821	------	1874	[9] 5, 400	1927	2, 141
1822	[2] 168	1875	[10] 5, 600	1928	1, 706
1823	------	1876	7, 196	1929	1, 536
1824	88	1877	6, 418		
1825	332	1878	4, 492	1930	1, 537
1826	479	1879	2, 800	1931	952
1827	2, 591			1932	910
1828	5, 553	1880	[11] 3, 940	1933	540
1829	6, 672	1881	[12] 5, 140	1934	234
		1882	5, 149	1935	286
1830	[3] 5, 970	1883	3, 410	1936	904
1831	6, 013	1884	5, 602	1937	1, 091
1832	6, 049	1885	1, 059	1938	320
1833	6, 796	1886	[13] 930	1939	388
1834	8, 662	1887	[12] 8, 428		
1835	9, 485	1888	6, 480	1940	445
1836	12. 756	1889	[13] 1, 818	1941	1, 345
1837	10, 872			1942	908
1838	[3] 12, 108	1890	[12] 2, 511	1943	1, 004
1839	13, 413	1891	3, 000	1944	1, 508
		1892	4, 740	1945	2, 261
1840	13, 425	1893	[14] 3, 000	1946	1, 861
1841	[4] 15, 988	1894	1, 370	1947	2, 318
1842	15, 939	1895	[15] 1, 300	1948	1, 807
1843	[5] 19, 574	1896	1, 300	1949	2, 046
1844	21, 864	1897	1, 300		
1845	27, 248	1898	1, 500	1950	1, 801
1846	[4] 25, 884	1899	1, 300	1951	1, 923
1847	27, 134			1952	3, 532
1848	[5] 23, 869	1900	1, 300	1953	3, 688
1849	[4] 22, 109	1901	[16] 1, 050	1954	3, 229
		1902	[15] 1, 300		
1850	19, 734	1903	1, 300	Total production	832, 365
1851	[5] 16, 594	1904	1, 300		
1852	[4] 14, 319	1905	1, 300		

[1] 1800–1820, inclusive: Estimated from very incomplete statistics (Ingalls, 1908, p. 120–124; Meeker, 1872, p. 271–296; Pike, 1810, p. 5; and Thwaites, 1895, p. 271–292). In 1810, 200 tons was shipped by the Indians to Prairie du Chien, Wis. alone (Thwaites 1895 p. 271–292). Probably additional tonnages were shipped elsewhere that year. Ingalls (1908 p. 120–124) estimated that "as much as 200 tons" was shipped annually from 1780 to 1820. From these and other incomplete records, the listed conservative estimates were made to point out that production began in this area in the 1700's rather than in 1823 as commonly thought.

[2] 1821–29, inclusive: In the report (Bomford, 1829, p. 128) by the Chief of the Army Ordnance Department, who was in charge of the lead mines, the 168 tons listed in later reports as production for the year 1823 alone, is given in Bomford's report as being produced from 1821 to September 30, 1823, inclusive. The 88 tons generally listed for 1824 in later reports, is listed by Bomford as the product of the period from October 1, 1823, to the end of 1824. As Bomford's document is the original source, it has been chosen over the many secondary sources. However, probably considerable lead was produced for which no royalty was collected by agents of the United States Government all through the early years of Land Office control, and therefore no record was obtained by the agents. For example, Dr. Moses Meeker (1872, p. 271–296), a prominent early settler, tabulated in detail 212.5 tons of lead that were produced near Galena, Ill., in 1823 alone, considerably more than the official tonnage of 168 tons for the period from 1821 to September 30, 1823. Likewise the tonnages produced in 1826–28, inclusive, as given by Chandler (1829) on his very early map, are about 500 tons in excess of the official Government statistics. However, the official records have been chosen for this report, as there are very few records of lead produced for only a few of these early years that show this probable excess above the production given in official Government statistics.

[3] 1830–40, inclusive: In Whitney (1854, p. 421); also in Hunt (1821–60); and in Winslow (1894, p. 146–147).

[4] 1841, 1842, 1846, 1847, 1849, 1850, and 1852: Statistical average of the amounts given by Whitney (1854, p. 421), Winslow (1894, p. 146–147), Hunt (1821–60), and Daniels (1854, p. 64).

[5] 1843–45; 1848, 1851, 1853; From Winslow (1894, p. 146–147), Whitney (1854, p. 421), Hunt (1821–60), and Daniels (1854, p. 64).

[6] 1854–57, and 1860: Hunt (1821–60) and Schubring (1926. Exhibit 1).

[7] 1858, 1859, and 1861: Estimated by taking the production from the end of 1851 to 1861, inclusive (Strong, 1877, p. 750), a total of 161,334 tons of metallic lead, and subtracting the tonnage recorded. The difference is 41,620 tons of metallic lead produced in the years for which records are missing (1858, 1859, and 1861). This tonnage has been distributed to these three years by estimations figured on the yearly decline.

[8] 1862–71, inclusive: The production of this 10-year period is calculated from the detailed production figures given by Moses Strong (1877, p. 743–750). These statistics were given in pounds of 80 percent lead concentrates, which were calculated to short tons of metallic lead. The Illinois and Iowa production is known to have been 75 percent of the production in Wisconsin during several of these years. This factor of 75 percent was used to calculate the estimated production in Illinois and Iowa where only general or incomplete statistics were available. The estimated Illinois and Iowa production was combined with the known Wisconsin production from 1862 to 1871 inclusive to arrive at the probable production of the entire district during this period.

[9] 1872 and 1874: From Strong (1877, p. 750).

[10] 1873 and 1875–79, inclusive: Data obtained from U. S. Geological Survey, (1883); agrees with Winslow (1894, p. 146–147).

[11] 1880: From U. S. Geological Survey (1883); also agrees with Schubring (1926, Exhibit 1).

[12] 1881–85; 1887, 1888, 1890–92, inclusive: From Eng. and Min. Jour. Statistical Supplement (1892 [1902]); also Gillette (1911), and Schubring (1926, Exhibit 1).

[13] 1886 and 1889: Calculated from Winslow (1894, p. 146–147) by converting short tons of "lead ore" (concentrate) to metallic lead using 80 per cent lead in the concentrate. A small tonnage was included for Iowa in 1889.

[14] 1893 and 1894: From Gillette (1911).

[15] 1895–1900, and 1902–05, inclusive: Estimates made from incomplete statistics and estimates of the average annual production by Bain (1906, p. 294).

[16] 1901: From Engineering and Mining Journal, Statistical Supplement (1901 [1902]).

[17] 1906: Schubring (1926).

[18] 1907–54, inclusive: Statistics from United States Geological Survey (1907–23), United States Bureau of Mines (1924–31), and United States Bureau of Mines (1932–54). In addition, a very small quantity of silver is a smelter byproduct of the ores (U. S. Bureau Mines, 1953 preprint, p. 2).

sudden marked rise after the first American settlement in 1821, the peak production in 1845–47, and the marked decline after that high point was attained are apparent on this graph.

ZINC PRODUCTION

HISTORY OF PRODUCTION

Production of zinc ore in the upper Mississippi Valley district began in 1859 and has been continuous except for 1862. Zinc mining in this area was preceded in the United States only by the mines in New Jersey. A small smelter was erected in 1859 at Mineral Point, Wis. This plant, commercially unsuccessful, was abandoned the same year. A second smelter, operated from 1866 to 1868, inclusive, produced some spelter, but this plant also was soon abandoned because it was more economical to smelt the ores in the coal fields than to haul coal to the mining area.

Most of the early mined ores were shipped to the Matthiessen and Hegeler Co. at LaSalle, Ill. Until 1867 zinc carbonate ore alone was used, but in that year 420 tons of sphalerite was shipped; the first zinc sulfide ore was produced from the Swift and Rooney mine at Leadmine, Wis. (Dugdale, 1900, p. 36). Production of sphalerite has exceeded smithsonite since 1873. Zinc carbonate mining continued until 1931 when the zinc oxide plant at Mineral Point, Wis., was permanently closed. Since then, only a few carloads of zinc carbonate and oxidized zinc-lead ores have been shipped, during the 1930's and about 1949.

Between 5,000 and 25,000 tons of high-grade concentrates (table 2) was produced annually from 1870 to 1905. About that time more efficient mining methods, gravity milling, and mechanical roasting with magnetic separation were developed. These technical improvements were so successful that the district rose to the rank of fourth most productive in the United States from 1906 to 1910, producing 7 percent of the country's zinc. Operators were able to mine much lower-grade ores and the tonnage of ore produced increased greatly as the mining and concentrating methods were improved. For example, ore production rose from 42,130 short tons in 1906 (table 2) to 1,144,130 tons in 1910. By 1916 it had further increased to 3,354,600 tons, which yielded 60,228 tons of recoverable zinc metal, the largest quantity of zinc produced in any year to date (1954).

The depression of 1921, after the First World War, caused many mines to close, and the mining industry in the district has never fully recovered. However, from 1922 to 1928, inclusive, the district still was the eighth most productive area, but it produced only 2 percent of the nation's zinc.

The tapering off and final cessation of zinc mining by the Wisconsin Zinc Co., the depletion of known reserves, and the drop in demand and market price at the end of the 1920's, resulted in a major drop in production. This lower level of production was maintained during most of the following decade (1930–40). The principal producers in this period were the Vinegar Hill Zinc Co. and, in the earlier part, the Rule Mining Co. (later the Badger Zinc Co.). Less zinc metal was produced in the late thirties than in any period since 1920. (See table below.) In 1938 the district ranked 16th in the United States. This was due to temporary cessation of operations by the Vinegar Hill Zinc Co. in order to build a custom flotation plant at Cuba City, Wis.

Completion of the flotation mill introduced a new period of rising production. Smaller mining companies were able to ship a low-grade concentrate or mine ore to the custom mill and reduce their operating costs. By 1944 the district had risen to the rank of twelfth, producing 2.4 percent of the nation's zinc. This rise in production was stimulated by the United States Government's base-metal subsidies, and it continued until 1945 when the district became seventh in rank nationally. By 1949 most of the smaller mines were closed, but production began from several new large mines and increased to 35,313 short tons of zinc metal in 1952, the largest quantity since 1919. Production dropped somewhat from 1953 to 1955 owing to unfavorable zinc prices, but increased notably in 1956. In that year the district had maintained its rank as seventh largest in the nation as a zinc producer. In 1956 the district produced 38,590 short tons of zinc metal, of which 24,065 tons were produced in Wisconsin and 14,525 tons in Illinois, per U. S. Bureau of Mines preliminary published data.

Tonnage and value of zinc and lead metal produced in Wisconsin and northern Illinois, from 1925–50, and in Iowa from 1917–54

[Data compiled from U. S. Bureau of Mines Minerals Yearbook]

Years	Zinc		Lead	
	Short tons	Value	Short tons	Value
Wisconsin				
1925–29	114,914	$15,787,634	8,726	$1,225,156
1930–34	47,775	3,922,158	4,173	336,064
1935–39	31,964	3,312,788	2,989	300,618
1940–44	51,370	10,068,720	4,780	692,400
1945–49	55,220	13,425,566	6,240	1,566,702
1950	5,722	1,625,098	532	143,640
Total	306,965	48,141,914	27,438	4,264,580
Illinois				
1925–29	5,503	$817,666	813	$136,852
1930–34	9	844	0	0
1935–39	0	0	0	0
1940–44	6,269	1,209,492	438	59,782
1945–49	31,308	7,762,914	3,556	1,043,346
1950	21,071	5,984,164	1,269	342,630
Total	64,160	15,775,080	6,094	1,582,610
Iowa				
1917	18	$3,672	34	$5,848
1918–53	0	0	0	0
1954	0	0	4	1,096
Total	18	3,672	38	6,944

Zinc ore and metal production in the district is given on table 2 and in figure 49. The value of this zinc production, on the basis of 15 cents per pound metallic zinc, would be $363,000,000. The combined lead and zinc production has been $616,500,000 to date in terms of the approximate average value of these metals in recent years. Nearly 85 percent of the zinc was mined in Wisconsin, 15 percent in Illinois, and a small amount in Iowa. In recent years, however, Illinois and Wisconsin have produced nearly equal quantities of zinc. (See above table on tonnage and value of zinc and lead metal produced.) The early production statistics are fairly complete, mainly through the efforts of Moses Strong (1877, p. 742–743). For the years 1876 to 1897, inclusive, the available information is very unsatisfactory, being for the most part only incomplete statistics. Since that time fairly complete records are available.

PRODUCTION FROM ZINC ORE BODIES

The zinc mines of the district are developed in ore bodies whose potentialities range from a few hundred tons to more than 3,000,000 short tons of zinc-lead ore.

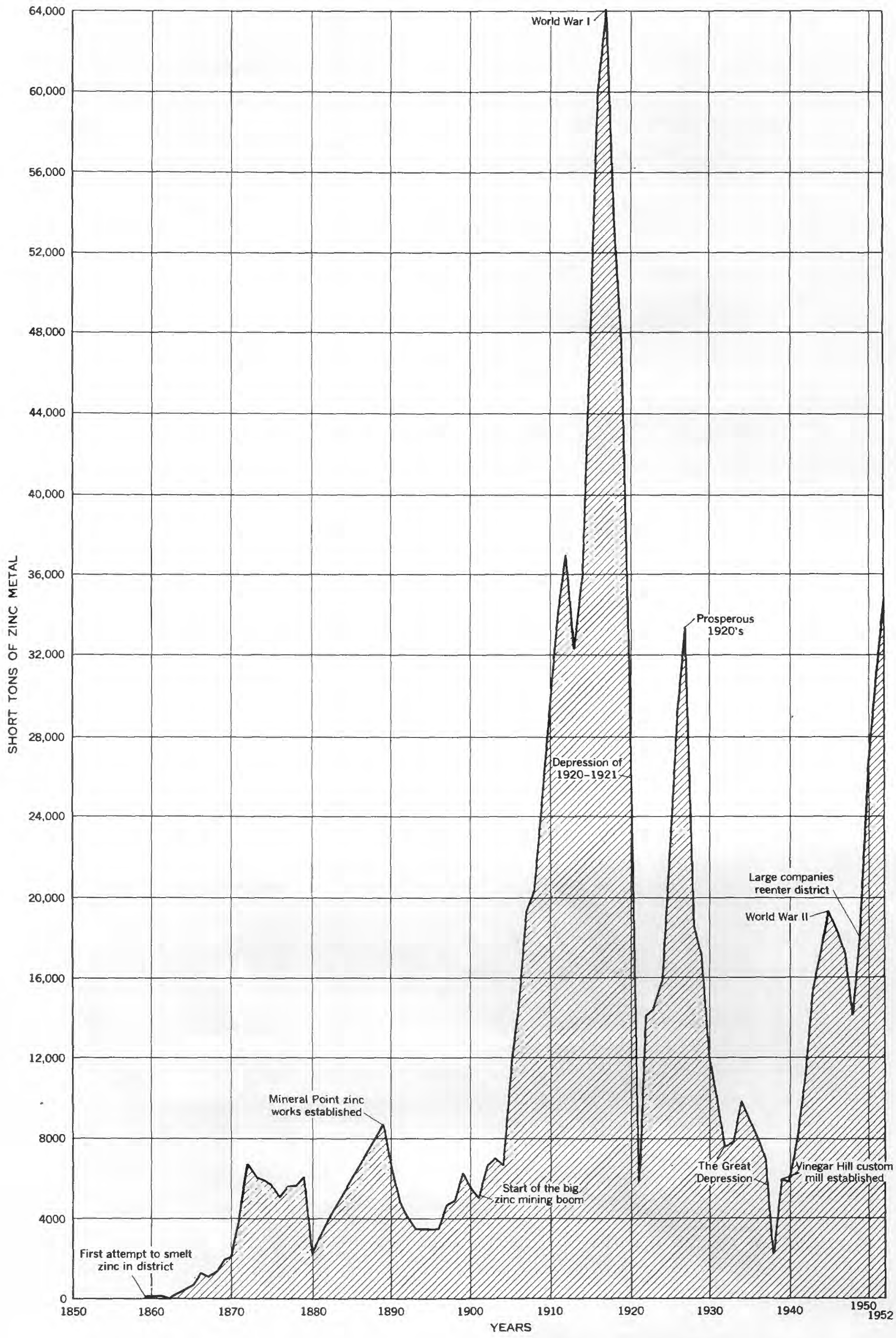


FIGURE 49.—Production of metallic zinc, correlated with historical events, upper Mississippi Valley district.

TABLE 2.—*Metallic-zinc and ore production in the upper Mississippi Valley district from 1859 to 1952*

[Footnotes 1-15 give the sources of the production data]

Year	Production, in short tons, of—		Year	Production, in short tons, of—	
	Ore	Metal		Ore	Metal
1859	[1] 9	[1] 3	1908	522, 599	20, 318
			1909	770, 614	25, 350
1860	[2] 160	[3] 56			
1861	113	47	1910	1, 144, 130	29, 572
1862	None	None	1911	1, 276, 753	33, 939
1863	560	196	1912	1, 511, 895	37, 115
1864	1, 586	455	1913	1, 525, 650	32, 346
1865	2, 099	732	1914	1, 648, 790	35, 924
1866	3, 687	1, 268	1915	2, 250, 000	46, 937
1867	3, 010	1, 155	1916	3, 354, 600	60, 228
1868	3, 700	1, 290	1917	3, 342, 740	64, 027
1869	5, 401	1, 890	1918	2, 658, 200	53, 806
			1919	2, 230, 200	47, 553
1870	5, 922	2, 033			
1871	12, 961	4, 370	1920	2, 054, 000	32, 005
1872	21, 976	6, 700	1921	217, 700	5, 816
1873	17, 814	6, 120	1922	287, 150	14, 076
1874	17, 313	5, 950	1923	540, 100	14, 429
1875	16, 208	5, 626	1924	800, 300	15, 670
1876	14, 675	5, 130	1925	1, 235, 700	22, 587
1877	[4] 16, 000	5, 600	1926	1, 685, 400	29, 377
1878	16, 000	5, 600	1927	1, 569, 000	33, 362
1879	[5] 17, 500	[5] 6, 123	1928	733, 500	18, 434
			1929	607, 100	17, 017
1880	7, 617	2, 266			
1881	[6] 9, 000	3, 100	1930	486, 400	12, 567
1882	11, 000	3, 800	1931	318, 700	10, 088
1883	13, 000	4, 500	1932	310, 300	7, 522
1884	15, 000	5, 200	1933	256, 400	7, 800
1885	17, 000	5, 900	1934	308, 600	9, 807
1886	19, 000	6, 600	1935	236, 000	8, 923
1887	21, 000	7, 300	1936	284, 800	8, 126
1888	23, 000	8, 000	1937	285, 000	6, 938
1889	[7] 24, 831	[7] 8, 691	1938	58, 700	2, 073
			1939	213, 400	5, 904
1890	[8] 18, 800	[8] 6, 600			
1891	13, 900	4, 900	1940	190, 436	5, 776
1892	[9] 6, 900	[9] 4, 128	1941	225, 637	7, 956
1893	[10] 10, 000	[10] 3, 500	1942	318, 211	11, 126
1894	10, 000	3, 500	1943	566, 483	15, 539
1895	10, 000	3. 500	1944	671, 804	17, 242
1896	10, 000	3, 500	1945	1, 108, 558	19, 318
1897	[11] 13, 703	[11] 4, 703	1946	1, 086, 330	18, 344
1898	14, 035	4, 911	1947	636, 399	17, 224
1899	18, 029	6, 310	1948	375, 190	14, 061
			1949	513, 063	17, 846
1900	15, 952	5, 583			
1901	14, 142	4, 950	1950	760, 733	26, 778
1902	19, 020	6, 657	1951	1, 025, 155	31, 403
1903	[12] 20, 000	[12] 7, 000	1952	1, 216, 655	35, 313
1904	[13] 19, 300	[13] 6, 755			
1905	[14] 32, 690	[14] 11, 442	Total production	44, 331, 543	1. 209, 965
1906	[15] 42, 130	[15] 14, 746			
1907	511, 860	19. 372			

[1] 1859; Hall and Whitney (1862, p. 371). The ore was estimated from the metal, which is listed as 2 or 3 tons, on the basis that the metal was about 35 percent of the original ore.

[2] 1860–78, inclusive: From Winslow (1894, p. 148–149). Derived from Strong (1877, p. 742–743). Also in Schubring (1926, Exhibit 2).

[3] 1860–78, inclusive: Derived from Strong (1877, p. 742–743) by Gillette (1911). Converted from ores on a basis that the average metal content of hand sorted ore was 35 percent zinc during these years.

[4] 1877: Estimated by averaging preceding (1876) and succeeding (1879) years. The metal content was converted from the estimated ores on a basis of 35 percent. (See note 3.)

[5] 1879: From Winslow (1894, p. 148–149). Statistics credited to "Irving" and to the "Census." The metal content was converted from the ores on a basis of 35 percent. (See note 3.)

[6] 1881–88, inclusive: Estimated. General estimates calculated on a sliding scale using the 1880 and 1889 statistics as end members. The metal content was converted from the estimated ores on a basis of 35 percent. (See note 3.)

[7] 1889: From Winslow (1894, p. 148–149) and Schubring (1926, Exhibit 2). The metal content was converted from the ores on a basis of 35 percent. (See note 3.)

[8] 1890 and 1891: Estimated. General estimates calculated on a sliding scale using the 1889 and 1892 statistics as end members. The metal content was converted from the estimated ores on a basis of 35 percent. (See note 3.)

[9] 1892: From Engineering and Mining Journal Statistical Supplement (1892 [1902]).

[10] 1893–96, inclusive: Estimated. General estimates made for these 4 years by averaging the production for 1892 and 1897.

[11] 1897–1902, inclusive: Schubring (1926, Exhibit 2). Essentially complete, as the statistics check closely with estimates by H. F. Bain and Mineral Industry. The metal content was converted from the ores on a basis of 35 percent. (See note 3.)

[12] 1903: Estimate by Bain (1905, p. 13). The metal content was converted from the estimated ores on a basis of 35 percent. (See note 3.)

[13] 1904: Estimate by Bain (1906), p. 9). Bain considered this estimate as "too low". Checks with U. S. Geological Survey (1905) and Engineering and Mining Journal Statistical Supplement (1905).

[14] 1905: Statistics from Engineering and Mining Journal Statistical Supplement (1906, p. 647). Bain and U. S. Geological Survey (1906) give the more general amount of 33,000 tons. The metal content was converted from the ore production on a basis of 35 percent. (See note 3.)

[15] 1906–52, inclusive: Statistics from United States Geological Survey (1906–23), United States Bureau of Mines (1924–31), and United States Bureau of Mines (1932–52). From 1950 to 1952 some of the metal statistics are preliminary, not final figures. In addition, small quantities of cadmium and germanium are recovered as smelter by-products of the ores (U. S. Bureau of Mines, 1953, preprint, p. 2).

Many mines produced from several ore bodies, but several mines have produced from different parts of a single ore body. Most of the ore bodies in the district contained less than 100,000 tons of zinc-lead ore, but most of the successful zinc-lead mines in the last 40 years have been operated in ore bodies that contained between 100,000 and 500,000 tons of zinc-lead ore. Ore bodies within this tonnage range are probably the smallest that have present and future major economic value. However, a considerable number of even larger ore bodies are known in the district. Many of these contained between 500,000 and 1,000,000 tons of zinc-lead ore; some, however, contained between 1,000,000 and 2,000,000 tons, and a few consisted of more than 2,000,000 tons of ore, but less than 4,000,000 tons.

In the following tabulation the mines are grouped according to average tonnage of ore produced, and the aggregate production for each group is given. A few lead, copper, and iron sulfide mines are included with the zinc-lead mines, as noted. Groups of mines in one ore body are listed together to give a more accurate picture of the size of the ore bodies.

The following 99 mines had an aggregate production of approximately 500,000 short tons of ore by 1957.

Argall
Beacon Light
Beadle-Dubuque & Lake Superior
B & C
Ben Hur
Big Ten
Brown
Brugh & Amsden [1]
Cardiff #2
Century
Chief of Police
Columbia
Corr-Crooked Six
Crow Branch
Cuba City
Curwen
Defense
Earl
Ebenezer
Ewing & Cook
Fairplay Level [1]
Fitzpatrick
Fourteenth St.
Glanville (Elizabeth) [1]
Haggerty [1]
Happy Home
Harris
Henrietta
Hibernia
Hird #1
Hird #2
Honest Bob
Illinois [1]
Imhoff
Imhoff-Egan
Joe Stegan [1]
John Vivian
Jug Handle
Kansas [1]
Kearns
Kingeter
Kivlahan
Krog & Webster
Kroll-Hornsnoggle-Old St. Anthony
Little Corporal
Little Dick

[1] Lead mine.

Lyght
Madison
McCann
McFeeley Level[1]
McMillan
Meekers Grove
Mermaid
Midway
Milner
Milwaukee-Highland
Moore's Level
New Dale Rundell
New Defense
New Gruno
New Occidental
Oakland
O'Brien
Ohlerking[1]
Old Cottingham
Old Occidental
Old Slack
Paul Graber
Pengelly
Pilot Knob
Pine Tree
P. M.
Preston Point Level[1]
Rajah
Richards (Berg)
Rico
Rockford Mining & Milling Company[1]
St. Anthony
Southwestern Wisconsin
Spring Hill
Steppler
Stewart & Bartlett[1]
Stratman
Strawberry Blonde
Temby[2]
Tippecanoe
Tommy Dodd
Tyrer
United
Vial
Victoria
Victory
Wallace
Weigle (Blockhouse)
Weiskircher
Western Star
Whaley
Whig-Edgerton
Wicks

The following 92 mines and ore bodies had an aggregate of about 4,000,000 short tons of ore by 1957.

Appleton
Atkinson[1]
B.A.T.
Baxter
Beach[2]
Bearcat (Hird)
Beloit-Elmo
Benton Star-Farrey
Best
Betsy
Blackjack (Beetown)
Capitola
Cardiff #1
Centerville-Red Jacket
Clayton
Coltman
Depp
Durango Drybone-Timber Range
Fields Upper Run
Four S. & B.
Galena Level
Graham & Stevens
Hazel Green
Hazel Patch
Hoare
Hofer (Boyle)
Holmes[1]
Hoover-Iowa-Imperial
Hugh Jones-Hendy, Gavey & Sobey[1]
Jack of Clubs
Jack of Diamonds
James-Little Elm
Koll
Lafollette-Last Chance-Washburne
Lawrence (Meekers Grove)
Leadmine
Level-Kilbourne-Kerrick & Jones[1]
Levens-North Langworthy[1]
Lewis & Lynch
Liverpool-Ross
Longhenry
Lyne
Masbruch
M. C.
McCabe
Meekers Grove Opencut[3]
Merry Xmas
Minter
Mitchell Hollow
Montfort
Murphy
New Birkett
New Longhorn
New Mulcahy
North Hoskins-New Hoskins-New Cottingham-Little Minnie
North Star
North Survey
Oldenburg
Old Gruno
Old McKinley
Oxman-Snowball
Paquette
Peaceful Valley
Penitentiary
Pittsburg (Ill.)
Pittsburg (Meek. Gr.)
Red Dog[1]
Roosevelt
Ross-Gribble-Stevens-E. Glanville
Rowley
Royal
Royal Princess
Scrabble Creek
Senator
Simpson
Skene
Spargo
Stewart's Cave[1]
Swift & Rooney
Ten Strike-Merry Widow
Tiffany
Trego (Tennyson)
Trio-Pode
Tripoli
Tunnel Hill
Vandeventer
Waters
Weigel (Linden)
Williams
Wilson-Gill
Winrock
Wishon[1]

The following 35 mines and ore bodies had an aggregate production of about 5,600,000 tons of zinc-lead ore by 1957.

Acme
Andrews
Birkbeck
Blewett
Coker #3
Connecting Links 1 and 2
Drum
Empress
Gilman
Grant Co.-Homestead
Helena-Roachdale
Hodge
Horseshoes 1 and 2
Hospital Run (Dodgeville No. 2)
Jarrett-Wicklow-Board of Trade
Jefferson
Lawrence
Lucky Hit
Lucky Twelve
Meloy (Fields)
M. & H.
Mulcahy
New Ida Blende
Nightingale
Northwestern
Ollie Belle
O. P. David
Pittsburg-Benton-Etna
Rodham
Sally Waters
Trego
Treloar-Harmony
Trewartha
Wilkinson

The following 28 mines and ore bodies had an aggregate total production of about 10,000,000 tons of zinc-lead ore by 1957.

Birkett
Blackstone
Blackstone (V. H.)
Booty
Byrnes
C. A. T.
Champion
Clark Range
Cleveland
Coughlin
Dall
Dark Horse-Optimo #1
Dodgeville-D. H. & S.-Ellis-New McKinley
Graham-Ginte
Gray
Indian Mound
Kittoe
Liberty-Big Dick
Monmouth-North Monmouth
New Mullen
North Hayden ore body
North Unity
Old Ida-Blende
Slack-Squirrel-Lucky Six-Peacock-Okay
South Hayden ore body
South Unity-Hughlett & Gray
Vinegar Hill
Wipet

[1] Lead mine.
[2] Copper mine.
[3] Iron sulfide mine.

The following 15 mines and ore bodies had an aggregate production of about 10,000,000 tons of zinc-lead ore by 1957.

Badger
Bull Moose-Middie
Copeland
Crawford
Crawhall-Thompson
Enterprise-Empire
Federal
Fox
Highland Kennedy-Franklin
Hoskins
Martin
Monroe-Longhorn-Little Joe
Old Winskell
Penna-Benton
Raisbeck-Gritty Six-Trego

The following 6 mines and ore bodies had an aggregate production of about 10,000,000 tons of zinc-lead ore by 1957.

Black Jack
Blockhouse Range
Coker No. 2
Frontier-Calvert-Treganza
Gensler-Winskell ore body
Linden Range

The following 5 mines and ore bodies had an aggregate production in excess of 12,500,000 tons of zinc-lead ore by 1957.

Bautsch
Coker No. 1
Graham-Snyder mine
James mine ore body
Kennedy-Little Dad-Big Dad

COPPER PRODUCTION

Small quantities of copper ore were produced in the district at various times from 1837 to 1949, inclusive. The first ore was mined about half a mile southeast of Mineral Point, Wis., and most of the ore came from this vicinity. However, ore was also mined and shipped from near Gratiot; along Plum Creek, a branch of the Kickapoo River, near Wauzeka; and at Mount Sterling, Wis. At one time four small furnaces near Mineral Point smelted this ore (Strong, 1877, p. 741).

Records of copper production are very incomplete (table 3). The total recorded tonnage is only 2,441 tons of ore, which averaged approximately 20-percent copper. However, probably several times this quantity was actually produced. Daniels (1854, p. 61) stated that 7,500 tons of 15- to 20-percent copper had been mined by that time at Mineral Point alone. Possibly the total production of copper ore is as much as 10,000 tons. The value of this copper production, in terms of recent copper prices calculated on the basis of 25 cents per pound metallic copper, ranges between \$195,000 for the minimum production of 2,441 tons of ore and \$800,000 for the maximum production of 10,000 tons.

IRON SULFIDE PRODUCTION

Iron sulfide was mined in the district at several places and also concentrated widely as a byproduct of lead and zinc production from 1899 to 1949. Pyrite and marcasite were the only products in a few mines,

TABLE 3.—*Copper-ore production, in short tons, in the upper Mississippi Valley district*

[Ore averaged 20-percent copper. Footnotes 1–17 give sources of available production data]

Year	Ore (short tons)	Year	Ore (short tons)
1832	(1)	1862–72	(7)
1833–36	(2)	1873–74	[8] 200
1837–40	[3] 685	1875	[9] 17
1841	[4] 19	1876	9
1842	306	1877–79	(10)
1843	420	1880	[9] 53
1844	388	1881–1911	(11)
1845	54	1912	[12] 40
1846	45	1913–35	(13)
1847–49	(5)	1936–40	[14] 5
1850	[4] 50	1940–47	(15)
1851–55	(5)	1948–49	[16] 3
1856	[4] 10	1950–52	(17)
1857–59	(5)		
1860–61	[6] 137	Total recorded production.	2, 441

[1] 1832: Schoolcraft (1834, p. 301) notes the discovery of copper at Mineral Point, Wis. by Mr. Ansley in 1832. Schoolcraft states prospect pits had already been dug but does not note any production of ore.

[2] 1833–36, inclusive: Copper ore was probably first produced in the district during these years, but no records of production are known.

[3] 1837–40, inclusive: Recorded in Hall and Whitney (1862, p. 364–368), and Strong (1877, p. 741).

[4] 1841–46, 1850, 1856, inclusive: From Chamberlin (1882, p. 569–571), and Strong (1882, p. 69–71). Most of the statistics are listed as hand-concentrated ore, but some are given as metallic copper. The latter have been converted back to ore by assuming that the ore averaged 20 percent copper, and that the recovery in the furnaces was 85 percent.

[5] 1847–49, 1851–55, and 1857–59, inclusive: No known records of production, but probably copper was produced during these years.

[6] 1860 and 1861: Strong (1877, p. 741) (1882, p. 69–71), and Hall and Whitney (1862, p. 364–368).

[7] 1862–72, inclusive: No record of production.

[8] 1873 and 1874: Strong (1877, p. 741).

[9] 1875, 1876 and 1880: Chamberlin (1882, p. 571).

[10] 1877–79, inclusive: No record of production although possibly, some copper was produced.

[11] 1881–1911 inclusive: No record of production. Some prospecting and perhaps mining was done on the Temby mine at Mineral Point, Wis. between 1906 and 1908, but no record is known of ore produced.

[12] 1912: Cox (1909, p. 592). This ore, when shipped in 1914, totaled 37 tons which yielded 10,300 lb. of copper and 16 ounces of silver (U. S. Geol. Survey, 1914, pt. 1, p. 122).

[13] 1913–35, inclusive: No recorded production.

[14] 1936–40, inclusive: Estimated from oral, communication from Prof. E. R. Shorey, University of Wisconsin, 1948. Sometime during these years, the University of Wisconsin mined a truckload or two of copper ore for ore dressing and metallurgical tests from the Gratiot copper mine (Cox, 1912, p. 592).

[15] 1941–47: No production.

[16] 1948 and 1949: Estimated. During these years, the owner of the Plum Creek copper mine (Strong, 1882, p. 69–70) started a quarry for agricultural lime at the site of the old mine. Copper was found in considerable quantities in the quarry and was sorted and gathered by the owner for shipment. The estimate was made by the U. S. Geological Survey from the ore piles.

[17] 1950–52 inclusive: No known production.

notably the Johns mine southwest of Montfort, and the Meekers Grove opencut mine at Meekers Grove, Wis. The latter mine produced 29,007 short tons of iron sulfide concentrates while operated by the Uniset Mining Co. in 1938.[16] Other mines, rich in iron sulfides, were operated chiefly for pyrite and marcasite and for sphalerite and galena as byproducts. Examples are the Washburn mine near Arthur and the Wilkinson mine east of Cuba City, Wis. The Wilkinson mine, probably the largest single iron sulfide producer, supplied most of the district iron sulfide ores from 1912 to 1915, inclusive. The production of this mine is given in table 4.

Many other zinc mines produced iron sulfide concentrates as a byproduct during the 50 years that sulfuric acid plants operated in the district. Most of the

[16] Data furnished by Vinegar Hill Zinc Co., Platteville, Wis., Feb., 1946. Published with permission.

TABLE 4.—*Production of iron sulfide concentrates, Wilkinson mine, Cuba City, Wis.*

[Data furnished by the Vinegar Hill Zinc Co. Published with permission]

Year	Short tons	Year	Short tons
1911	1,454	1915	4,201
1912	13,878		
1913	19,929	Total	53,010
1914	13,518		

iron sulfide was used within the district to manufacture sulfuric acid, but small tonnages of concentrates were shipped from the district.

At least two sulfuric acid plants were operated in the district between 1899 and 1949. One of these plants, that of the Mineral Point Zinc Co., Mineral Point, Wis., operated from 1899 to about 1930; the other plant, that of the Vinegar Hill Zinc Co., Cuba City, Wis., operated from about 1915 to 1949. Both plants are now dismantled and since 1949 the iron sulfides are not recovered.

Data on iron sulfide production are very incomplete, but the available production is given in table 5.

TABLE 5.—*Iron sulfide concentrate production in the upper Mississippi Valley district from 1899 to 1949*

[Footnotes 1–8 give sources of production data. Production given in long tons (2,240 pounds)]

Year	Long tons	Year	Long tons	Year	Long tons
1899–1905	(1)	1913	25,328	1924	7,942
1906	[2] 4,000	1914	14,188	1925	(7)
1907–09	(3)	1915	13,985	1926–37	(8)
1910	[4] 12,555	1916–21	(5)	1938	[8] 29,007
1911	12,893	1922	[6] 3,808	1939–49	(8)
1912	17,898	1923	9,197		

[1] 1899–1905, inclusive: The sulfuric acid plant at Mineral Point, Wis. was completed in 1899. Apparently this plant was operated nearly continuously from that year until about 1930. Therefore the production of iron sulfides began in 1899, and some ore of this type was probably utilized every year between that year and 1906, the first one in which production is recorded. The volume produced annually during this period was possibly between 5,000 and 15,000 long tons of pyrite concentrates based on the production for 1906, 1910, 1911.

[2] 1906: The Johns mine at Montfort was reported to be producing about 400 long tons of iron sulfide concentrate per month in 1906 (The Telegraph-Herald, 1906, p. 126). Very probably other mines were also producing pyrite for the Mineral Point Plant so that the district production may have been 2 or 3 times the amount shown for the Johns mine.

[3] 1907–09, inclusive: Some production in the district, probably between 5,000 and 15,000 long tons annually, which was mostly shipped to the acid plant at Mineral Point, Wis.

[4] 1910–15, inclusive: Statistics from United States Geological Survey's (1912, 1913, 1914, 1915) Mineral Resources of the United States.

[5] 1916–21, inclusive: No data, although there was some production (United States Geological Survey, 1916–22). This production probably ranged between 2,000 and 15,000 long tons annually. The ore was shipped to the acid plants at Mineral Point and at Cuba City, Wis.

[6] 1922–24, inclusive: Statistics from United States Bureau of Mines (1927). 190 long tons of concentrates were shipped in 1923 and 120 long tons in 1924. The rest of the concentrates were used locally for acid.

[7] 1925: 40 tons of concentrates were shipped and acid was produced but the ore used for acid is not given (United States Bureau of Mines, 1927). Probably the district production was between 5,000 and 10,000 long tons of concentrates.

[8] 1926–49: No statistics available for iron sulfide concentrates used in acid production except from the Uniset mine in 1938. Additional concentrates were produced from zinc-lead ores that same year. During most of this period ore was shipped to or concentrated by the Vinegar Hill Zinc Co. annually at Cuba City (United States Bureau of Mines 1926–31, 1932–50). The plant was abandoned in 1949 and dismantled about 1955.

BARITE PRODUCTION

A small amount of barite was mined and concentrated in the district from 1919 to 1930, inclusive, except for 1922 (United States Geological Survey, 1919–23, United States Bureau of Mines, 1924–31). Exact figures are not available for this production, except in the year 1930 when 5,095 short tons of concentrates were produced.

Most of the barite came from the area between Meekers Grove and Leadmine, Wis. The principal mines were the Raisbeck at Meekers Grove, and the mines of the Porter Mining Co. in the NE¼NW¼ sec. 34, and NE¼NE¼ sec. 33, T. 2 N., R. 1 E., 2 miles south of Meekers Grove.

The Porter Mining Co. mined barite from 1919 to 1921, inclusive, and possibly from 1923 to 1930. A small production was shipped during these years, and no other company is known to have operated previous to 1929.

In 1929 and 1930, barite was mined also from the Raisbeck mine[17] at Meekers Grove, the ore being concentrated and separated from the accompanying lead ore by a small jig mill. About 1,000 tons was shipped during these two years. Galena was sold separately. The barite from the Raisbeck mine sold for $5 to $6 per ton and paid for the mining costs, the accompanying lead concentrate being clear profit. The ratio was 5 or 6 tons of barite to 1 ton of lead. The barite was sold for lithopone paint, and according to Snow, tests showed that the low-silica barite of this district refracted more easily than the high-silica barite from Missouri.

IRON PRODUCTION

Limonite and hematite have been mined in several localities in Richland, Vernon, Sauk, and Crawford counties, Wis., and in Dubuque county, Iowa. The ores are oxidation products of pyrite and marcasite. They have been mined in Wisconsin from the sandstones of Cambrian age (Strong, 1882, p. 49–56) and in Iowa from the Galena dolomite where they were accompanied by some lead ore (Calvin and Bain, 1900). The tonnages produced have been small, but the deposits in Wisconsin supplied a small charcoal iron furnace at Ironton, Wis. from 1857 to after 1880, and a second furnace at Cazenovia, Wis. from 1876 to 1879.

The largest iron mine in southwest Wisconsin is the Ironton mine, Ironton, Wis. in the SW¼, sec. 10, T. 12 N., R. 3 E., which was operated nearly continuously from 1850 until some time after 1880. Up to 1873 this mine had produced about 25,000 tons of 40 to 59 per cent of sorted iron ore yielding 11,000 tons of pig iron (Strong, 1882, p. 49–56). Small tonnages of ore were produced from the following mines between 1870 and 1900: (1) A mine in the SW¼ sec. 7, T. 10 N., R. 1 E.; (2) a mine in the NE¼, sec. 3, T. 12 N., R. 2 E.; (3) the

[17] Snow, William, former barite-mine operator, oral communication, 1946.

mine of the Kickapoo Mining Co. in the NE¼, sec. 10, T. 11 N., R. 3 W.; (4) the Taylor mine in the NW¼, sec. 8, T. 14 N., R. 3 W.; (5) a mine in the SE¼ sec. 13, T. 11 N., R. 4 E., all five in Wisconsin; and (6) the Durango Iron mine, Dubuque Co., Iowa in the SW¼ sec. 6, T. 89 N., R. 2 E.

GENERAL FEATURES OF THE ORE DEPOSITS

Thousands of small lead mines, about 400 zinc mines, and a few small copper, iron, and barite mines constitute the upper Mississippi Valley zinc-lead district (pl. 1). The ore bodies occur chiefly in the Galena dolomite, and in the limestones and dolomites of the Decorah and upper part of the Platteville formations, all of Middle Ordovician age. Mineable deposits have been found locally in the Prairie du Chien group of Early Ordovician age, and small deposits of lead and iron sulfides have been found in the strata of Cambrian and Silurian age.

The ore deposits in the Middle Ordovician rocks are divisible into 3 classifications: (1) "gash-vein" [18] deposits (fig. 50), (2) "pitch-and-flat" deposits, and (3) placer and residual deposits. The gash-vein deposits are in the Galena dolomite. Galena is the principal ore, but less commonly sphalerite, smithsonite, or chalcopyrite and its weathering products are present in mineable quantities. The ores in the gash-veins are deposited in veins along vertical joints and in porous vuggy horizontal areas (locally called "openings") along these joints. The "pitch-and-flat" deposits are in the lower part of the Galena, the Decorah, and the upper part of the Platteville formations. Sphalerite is the main ore mineral, but pyrite and marcasite are abundant and galena is in smaller quantities than sphalerite. Barite is the main ore mineral in a few deposits that lie east of Cuba City, and north of Belmont, Wis. (Apell, 1949a). Copper is present east of Mineral Point and near Highland, Wis., in possibly commercial quantities deposited with sphalerite. In the pitch-and-flat deposits, the ores form banded veins within minor faults and fractures, and also replacements of rocks adjacent to the fractures. The pitch-and-flat ore bodies may be further subdivided into "linear-" and "arcuate-type" ore bodies (fig. 50) which are structurally similar except in certain details, but differ only in pattern.

The main primary minerals of the deposits are quartz, dolomite, pyrite, marcasite, sphalerite, galena, chalcopyrite, barite, and calcite. The ore deposits are distinctive, because of the presence of cryptocrystalline quartz, the lack of high-temperature minerals, and their banded, reniform sphalerite, pyrite, marcasite, and barite. Most of the ores show crustification and crystallization in open cavities. The minerals are deposited in a regular paragenetic sequence in veins, but also considerable metasomatic replacement of the wall rock has taken place. The ore bodies are closely associated with folds, faults, and joints and commonly fill small faults and joints.

Limestones and some of the dolomites that border the fractures of the ore bodies have been partly dissolved in many places. This removal of the carbonates leaves a residue of interstitial argillaceous materials and produces considerable thinning of the beds. The thinning by solution is most abundant in areas of strong deformation and tends to open and accentuate by minor slump the previously formed fractures and folds. Locally, collapse structures are formed by solution-slump.

In addition to leaching the carbonate rocks, the mineralizing solutions in the early stages of deposition silicified and then dolomitized the preexisting rocks. Locally, rocks normally calcareous within and bordering the ore deposits are completely altered to massive chert and dolomite but retain the original textures. Various degrees of incomplete replacement are common. The rocks of the underlying Prairie du Chien group, which contain a few known ore deposits, have undergone even more intense dolomitization and silicification than the overlying strata containing the principal ore deposits. In one deposit, at least, sericite flakes have been deposited in small vugs in the silicified wall rock of the ore body.

All Paleozoic sedimentary rocks in the district are known to contain some sulfide deposits. Widely spaced minor deposits of galena and iron sulfides fill vertical joints as gash-veins in the Silurian dolomites. Iron sulfides in small quantities, as well as minor amounts of galena, sphalerite, and barite, are of widespread occurrence in the Maquoketa shale, particularly in the basal beds, although no commercial deposits are known.

The Galena dolomite, which underlies the Maquoketa, is the uppermost of the three formations that contain the principal ore deposits of the district. The ore minerals in this formation have been deposited as gash-veins in joints or lining solution cavities, and as veins along bedding-plane and reverse faults in the lower part of this formation. Galena is the predominant sulfide in the upper beds of the Galena dolomite, and sphalerite

[18] The term "gash-veins" for the joint-controlled lead deposits was proposed by Whitney (1854, p. 48) (Hall and Whitney, 1858, p. 437–438) and later used by Winslow (1894, p. 140) and Chamberlin (1882, p. 453–454). Whitney states: "The term 'crevice,' as generally applied, in the lead region . . . designates the vein-like fissures, or gash-veins as they may be termed, in which the ore is found . . .". Winslow notes: "To these openings [vertical ore-bearing joints] the name of 'gash-vein' so generally given to the deposits of this region [Wisconsin] more particularly applies."

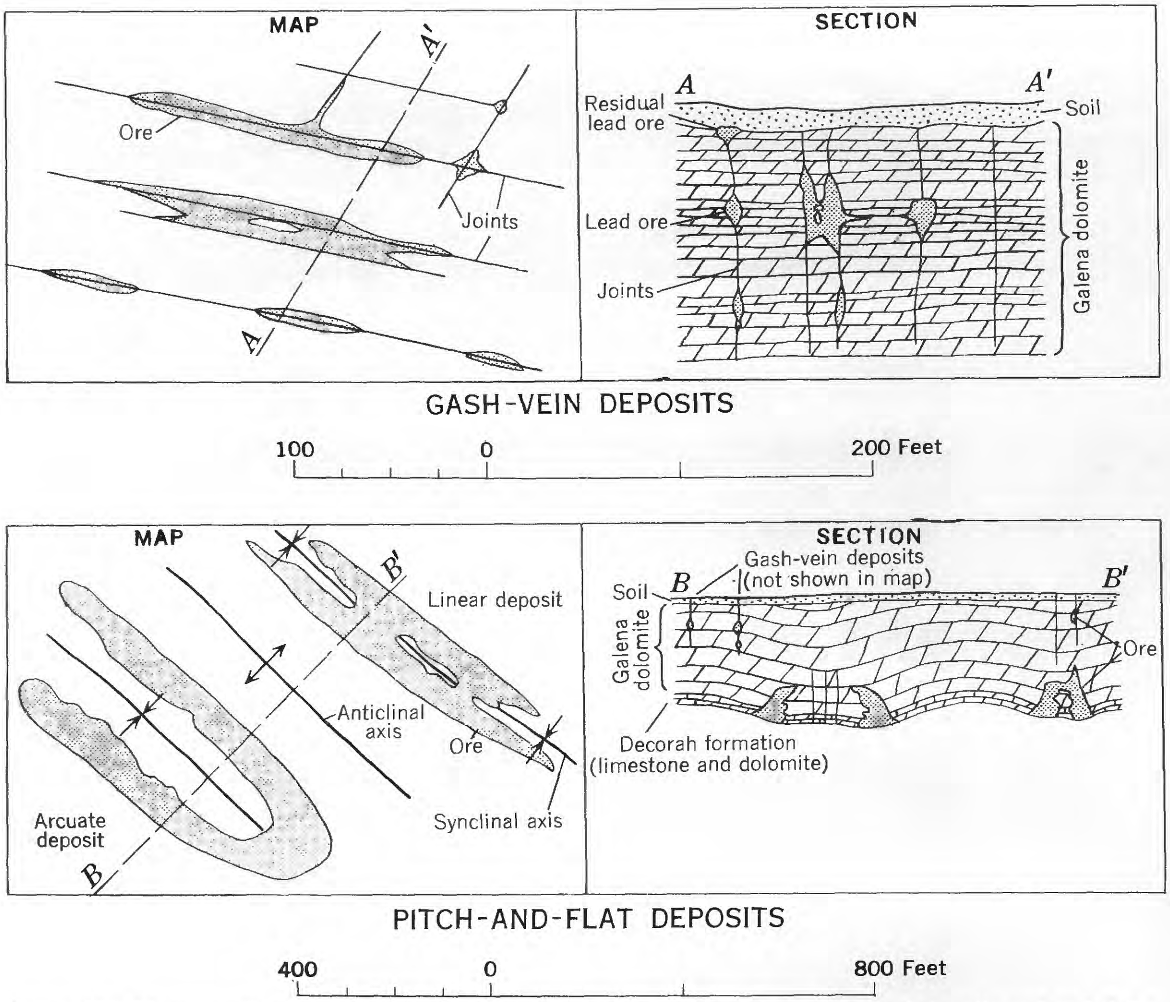


FIGURE 50.—Diagrammatic plans and sections illustrating typical patterns of gash-vein lead deposits and underlying pitch-and-flat zinc deposits of the arcuate and linear types, and their stratigraphic position to one another.

and considerable galena are most abundant in the lower beds of the formation. Where Galena dolomite is weathered near the surface, the clusters of crystals and veins of ore have commonly broken free from the rock walls and are found in loose masses in the dolomite sand or residual clay produced by weathering. Not all veins are simple fracture-fillings, but replacement of the wall rocks by sulfides is prevalent; also replacement veins bordering on one or both sides of initial, thin fractures are not uncommon.

In the dolomitic Ion dolomite member of the Decorah formation, the ore is generally restricted to fracture-fillings, replacement veins, and disseminated replacement crystals in veins marginal to the fractures. In the underlying shaly Guttenberg limestone member, similar vein-fillings are abundant, but replacement and impregnation crystals are equally common. The principal ore-bearing fractures in the Decorah formation are the bedding-plane and reverse faults typical of the main linear and arcuate types of zinc deposits (fig. 50). Zinc and iron sulfides are the most abundant minerals. The thin Spechts Ferry shale member at the base of the Decorah formation, where mineralized, commonly contains disseminated replacement and impregnation crystals of the sulfides.

The basal part of the principal ore-bearing beds consists of the upper part of the Platteville formation, which includes the Quimbys Mill and McGregor limestone members. The ore in the brittle Quimbys Mill (or so-called glass rock), member is generally found as veinlets in rock breccias, disseminated crystals replacing the rock, and veins along bedding-plane and minor reverse faults. A thick horizontal vein, or flat, is generally present along a bedding-plane fault in the basal carbonaceous shale layer of this member. In the McGregor member beneath, disseminated replacement ore and fracture-fillings are of about equal abundance.

The Pecatonica dolomite member is generally barren except for local minor concentrations of replacement iron sulfides and calcite. The basal, sandy Glenwood shale member of the Platteville formation commonly contains pyrite over wide areas and more locally galena and sphalerite, all of which may impregnate the shale and cement the quartz sand grains.

The St. Peter sandstone is pyritized in areas beneath many zinc deposits (Heyl, Lyons, Agnew, 1951; Kelly, 1949). Here too the pyrite is generally interstitial and cements the sand grains. Very small quantities of galena and sphalerite have been noted with this pyrite.

The Prairie du Chien group contains deposits of lead, zinc, copper, and iron sulfides. In areas where this formation is exposed in the district, these deposits are less abundant and rarely commercial; but results of drilling in 1950 by the U. S. Geological Survey (Heyl, Lyons, Agnew, 1951) indicate that zinc and iron sulfides were widely deposited, in small amounts at least, in this formation beneath the main district. These deposits appear to represent two types: (1) fissure veins along vertical joints or faults, and (2) veinlets, disseminations, and crystal-lined vugs in large brecciated zones, in places nearly directly underlying deposits in the Galena, Decorah, and Platteville strata.

A few mineralized areas have been found in the sandstone of Cambrian age. In a drill hole at Montfort, Wis., drilled by the U. S. Geological Survey, much pyrite and a little sphalerite interstitial to and cementing the sand grains of the Trempealeau formation were observed. A fissure vein of galena was mined many years ago along a vertical fault in the Dresbach sandstone at Dresbach, Minnesota (Emmons, 1929, p. 265–266).

Within the district a considerable variation is recognized in the relative quantities of the sphalerite, galena, and iron sulfides in the veins; also, variations in relative amounts of barite, calcite, and copper sulfides are characteristic. These variations occur not only in individual ore bodies, but may, in a general way, be characteristic of all the ore bodies in a given area.

The gash-vein deposits, though small, commonly contain a predominance of galena with some iron sulfide or oxide, and in a few places such as near Dubuque, Iowa and Potosi, Wis., they contain enough zinc as carbonate or sulfide so that zinc has been recovered as a byproduct. East of Mineral Point copper was the principal ore.

The pitch-and-flat zinc ore bodies commonly range between 3 and 10 percent zinc, but some rich pockets contain as much as 20 or 25 percent zinc. The average zinc content of the ore bodies is probably about 5 percent, and the average lead content is about 0.5 percent. However, the lead content in certain lead-rich ore bodies may run as high as 5 or 6 percent, adding greatly to the value of the ore. The zinc ores of the district in the vicinity of Highland and Centerville, Wis. (pl. 1) average about 2 percent lead, and those near Dodgeville, Linden, Mineral Point and Shullsburg, Wis., average about 1 percent lead.

The iron content ranges from amounts about equal to the zinc in low-iron ore bodies (between 1 and 10 percent iron) to as much as several times that of the zinc (between 15 and 30 percent iron). Vein-type ore bodies generally range between 8 and 15 percent iron. Disseminated ore bodies usually have a low iron content, between 1 and 10 percent iron.

The original limits of the mineralized district are not known except in a small area in the northwest part (Heyl, Lyons, Agnew, Behre, 1954). Most of the edges of the district are hidden either by overlying Silurian and late Ordovician rocks, as to the southwest in Iowa and to the south in Illinois (pl. 1), or by Pleistocene glacial deposits, as to the southeast and east, or are obscured by the erosion of the most favorable beds for ore deposition as to the northeast and north. On the northwest perimeter of the district, the actual margin of the mineralized area can be seen; here ore deposits are small, lean and widely spaced and are composed chiefly of calcite, with small quantities of galena, marcasite, and pyrite.

Many areas of closely spaced mines lie within the district. Between these areas only a few deposits are known (pl. 1). Factors that determine the known size and location of the areas of closely spaced mines are: (1) concentration of ore deposits, (2) erosion of the favorable beds locally, (3) patches of overlying rocks hiding the favorable beds, and (4) lack of prospecting.

MINERALOGY

The main commercial ores of the district are those mined for zinc, lead, and sulfur. The principal zinc ore mineral is sphalerite, but smithsonite and hemimorphite were formerly major sources of zinc. Galena, the only important lead ore, is in considerably lesser quantity than sphalerite in the ores mined since 1900. Cerussite was formerly mined in small amounts with the galena. Both pyrite and marcasite have been mined for the manufacture of sulfuric acid. Copper minerals were at one time mined on a small scale, and a small quantity of barite also was once produced.

The mineral suites are less simple than previously described. The following list of minerals found in the ore deposits is arranged according to the Dana system.

TABLE 6.—*Minerals of the Wisconsin-Illinois-Iowa zinc-lead district*

[Mineral names preceded by an asterisk (*) are not listed in older reports]

Primary minerals	
Gold	*Cobaltite or safflorite
Galena	Marcasite
Sphalerite	Calcite
Wurtzite	*Dolomite
Pyrrhotite	*Ankerite
*Millerite	*Quartz
Chalcopyrite	*Muscovite (sericite)
Pyrite	Barite
Secondary minerals	
Sulfur	Cerussite
Copper	Malachite
Chalcocite	Azurite
*Covellite	*Aurichalcite
*Greenockite	Hydrozincite
Bornite	*Hemimorphite
*Bravoite (?)	*Sauconite
*Violarite	*Zincian montmorillonite
Cuprite	*Pyromorphite
*Tenorite	*Vivianite
Hematite	*Erythrite (?)
Pyrolusite	Anglesite
*Honessite	Gypsum
Limonite	Epsomite
Psilomelane	Goslarite
Smithsonite	Melanterite
*Aragonite	*Copiapite
Miscellaneous minerals [Minerals that in some places were deposited under conditions unrelated to the deposition of the ores]	
Hematite	*Aragonite
Limonite	Quartz
Psilomelane	*Opal (hyalite)
Calcite (travertine)	*Glauconite and celadonite
Dolomite	

DETAILED DESCRIPTION OF MINERALS

NATIVE ELEMENTS

Sulfur (*S*).—Small quantities of powdery native sulfur have been found along fractures or in small cavities in the lead mines. The sulfur was undoubtedly formed by the decomposition of primary pyrite and marcasite. Minute, pale yellow, transparent crystals were noted in cavities in galena on old waste piles in the northeast corner of the SW¼SW¼ sec. 7, T. 1 N., R. 1 E., Lafayette County, Wis.

Gold (*Au*).—Gold was reported (Hershey, 1899, p. 240–244) in small "rose quartz nodules" in the topmost beds of the Galena dolomite just north of "Erin Mound", west of Eleroy, Stephenson County, Ill., in the NE¼SE¼ sec. 14, T. 27 N., R. 6 E. Individual nodules are reported by Hershey to have assayed 4.04 ounces of gold per ton. It is associated with galena, sphalerite, pyrite, marcasite, barite, and copper.

A single flake of native gold, 1 mm in length, was found by U. S. Geological Survey geologists on April 7, 1948, in a churn-drill sample of U. S. Bureau of Mines drill hole 30 at the Nigger Jim lead-barite prospect in the NE¼SW¼ sec. 32, T. 4 N., R. 1 E., Wisconsin. The gold was observed in the drill-hole sample recovered from a depth of 15 to 20 feet, in the Guttenberg limestone member of the Decorah formation, and was accompanied by galena, barite, and pyrite.

Copper (*Cu*).—Native Copper as a near-surface oxidation product, and other copper minerals were found in sec. 36, T. 2 N., R. 3 E., 4 miles northwest of Gratiot, Wis. (Cox, 1909, p. 592), and at "Erin Mound" west of Eleroy, Ill., in the NE¼SE¼ sec. 14, T. 27 N., R. 6 E., accompanying sphalerite, galena, pyrite, marcasite, barite, and possibly gold, in the uppermost beds of the Galena dolomite (Hershey, 1899, p. 240–244, Cox, 1914, p. 80–81).[19]

SULFIDES

Galena (*PbS*).—Galena has been found in all parts of the district and is the ore mineral of most widespread occurrence. It is deposited as symmetrically banded veins in the lead-bearing joints; in places central vugs are lined with cubic crystals, forming what is known locally as "cog ore" (fig. 51). In the gash-vein deposits, galena is found also as irregular crystalline masses filling the cavities of dolomite breccias.

In the pitch-and-flat ore bodies, galena is in the form of (1) dendritic intergrowths with sphalerite; (2) well-formed cubic crystals and some octahedral crystals embedded in marcasite, calcite, and barite; (3) crystals lining open vugs in the central parts of the veins; and (4) disseminated grains and crystals in the host rock. Commonly the galena is coarsely crystallized and in some places strongly sheared. A rare "stalactitic" form of galena has been found that has a central tube and crystal faces on the outer surfaces. The galena contains small amounts of silver.

Chalcocite (Cu_2S).—Chalcocite is a locally abundant secondary mineral produced from primary chalcopyrite by oxidation. Chalcocite has been mined with other copper ores near Mineral Point, Wauzeka, and Gratiot, Wis. It occurs in quantity also at the Eberle mine in the NW¼NW¼ sec. 2, T. 6 N., R. 1 E., southeast of Highland, Wis., and on the Steppler farm in the SE¼NE¼ sec. 7, T. 6 N., R. 1 E., at Centreville, Wis. Small quantities have been found in many other parts of the district.

[19] Cox, G. H., 1908, Field notebook 5, Wisconsin Geol. and Nat. Hist. Survey, Madison, Wis., p. 54.

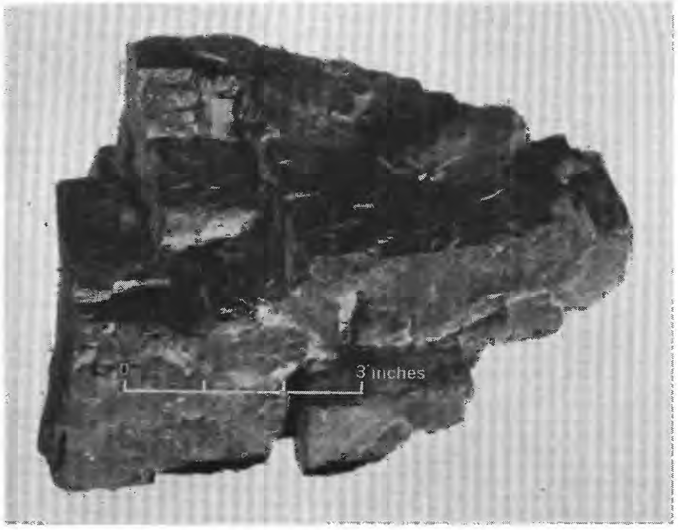


FIGURE 51.—Large cubic crystals of galena. They illustrate the coarsely crystallized habit typical of the galena crystals lining the central vugs of the gash veins. From New Hoskins mine, Leadmine, Wis.

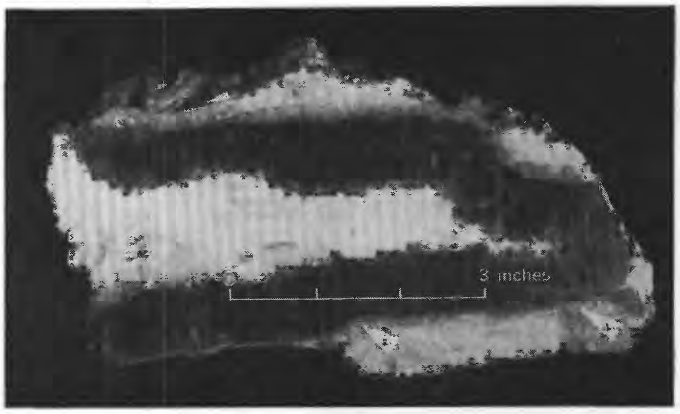


FIGURE 52.—Typical banded vein of primary ore. Note the two thick layers of dark radiating concentrically-banded sphalerite near each vein wall. The central sphalerite surfaces show crystal faces with later calcite deposited upon them. Pyrite (dark grains) locally replaces the dolomitic wall rock (at point 1), and a thin film of pyrite was deposited along both vein walls (at point 2). Locality: Liberty mine, Wis.

Sphalerite (*ZnS*).—Sphalerite is the most abundant zinc mineral in the district. Most commonly it is found below water table, and is altered to smithsonite above the water table. The sphalerite is deposited in symmetrically banded veins (fig. 52) which fill and also replace the walls of the reverse and bedding-plane faults and other fractures, and line vugs accompanied by other sulfides and vein minerals. The bands of sphalerite most commonly lie near the walls of the veins, and the surfaces toward the center of the vein nearly always show crystal faces. In many veins the sphalerite occurs in botryoidal, concentric masses composed of radiating crystals. Commonly it is rather fine grained and strongly banded, and the crystals are elongated at right angles to the surface of the sheet or cluster. Some of this type of "sphalerite" may actually be wurtzite, or a pseudomorph after wurtzite (see "wurtzite" below).

Sphalerite is also found (1) as large individual crystals; (2) as botryoidal groups of crystals; and (3) as impregnations or replacements within the rocks, particularly in the Platteville or Decorah formations. It also fills solution cavities and cements rock breccias.

Elongated, radiating crystals of sphalerite around a central, tubular aperture have formed stalactitelike masses. Minerals of later deposition, such as marcasite and galena, are deposited on the surface of the sphalerite and in the central aperture. These stalactitelike masses rise from the floor of the vug, cover the sides, or more rarely, hang from the roof.

Most of the sphalerite is reddish brown or dark brown, but some is black, owing to contained iron and possibly manganese. Much of the later-deposited sphalerite is lighter brown in color. A little is red, yellow, grayish blue, and even deep purple.

Analysis of a sample of pure sphalerite from the Calumet mine at Shullsburg determined the following quantities of zinc and iron:

	Percent
Zinc	63.8
Iron	2.35

Analysis furnished by the Calumet Corp., Shallsburg, Wis., March 1950.

The sphalerite is a primary vein mineral and is in greatest abundance in the central part of the district, becoming less abundant or absent toward the extreme limits of the district. Most of the sphalerite is in the pitch-and-flat deposits, but it is locally in the gash-vein lead deposits.

Greenockite (*CdS*).—This mineral is rare, but occurs as bright yellow crusts between cleavage planes of calcite next to partly leached sphalerite and as coatings on sphalerite crystals in the zone of oxidation. It has been observed in the Liberty mine in the NE¼ sec. 16, T. 2 N., R. 1 E., at Jenkinsville, Wis.; in the Trego mine at the north limits of Platteville, Wis.; at the Gray mine, 3 miles south of Galena, Ill.; and in the Dodgeville mine in Dodgeville, Wis.

Wurtzite(*?*) (*ZnS*).—The colloform, radiated-bladed habit of much of the zinc sulfide in the district is characteristic of the hexagonal form, wurtzite. Concentric fractures in such masses are not generally continuous, but the successive shells are definitely separable, and the resulting habit strongly suggests collodial precipitation (fig. 52). Concentric, alternating bands of light and dark zinc sulfide are present in many places; the boundaries between successive shells may be partly marked by minute iron sulfide crystals or minute cavities. Behre (in Bastin, 1939, p. 115) has suggested that it is "probable that the primary ore was originally altogether wurtzite." Petrographic studies conducted by Behre showed local extinction and a suggestion of aggregate polarization, while X-ray studies carried out by Paul F. Kerr of Columbia University showed isotropism, "but for various reasons Professor Kerr believes that the zinc sulfide represents wurtzite that has gone over into sphalerite during the grinding for X-ray photography" (Behre, in Bastin, 1939, p. 115).

Pyrrhotite (FeS).—Pyrrhotite was noted by J. W. Allingham (oral communication, 1957) associated with pyrite in the zinc ore from the Grey property near Mineral Point, Wis.

Millerite (NiS).—Millerite is a fairly common, late, primary sulfide mineral in the Quimbys Mill member of the Platteville formation in the pitch-and-flat ore bodies near Linden, Wisconsin (fig. 53). It is present as bronze-yellow radiating acicular needles that are partly altered to black, and yellow, orange, or green oxidation products. Clusters of millerite crystals developed in open vugs in the central parts of veins after the other sulfides were deposited, and most of the millerite was surrounded later by coarsely crystalline calcite. A detailed study of millerite and other nickel minerals in the ores is in progress (Heyl, Milton, Axelrod, 1956).

Small quantities of millerite have been noted, for example: (1) at the James mine in sec. 9, T. 1 N., R. 2 E., (2) near Shullsburg, Wisconsin, and (3) at the Dodgeville No. 2 mine, Dodgeville, Wis. Pseudomorphs of violarite after millerite are present at the Farrey mine along Wisconsin State Highway 11, in the NE¼NW¼ sec. 14, T. 1 N., R. 1 E., at Leadmine.

Bornite (Cu_5FeS_4).—Cox (1909, p. 592) reported bornite associated with other copper minerals at the copper prospect 4 miles northwest of Gratiot, Wis., in the center of the NW¼ sec. 36, T. 2 N., R. 3 E. It was also reported by Strong (1877, p. 692) at the copper mines near Mineral Point, Wis.

Chalcopyrite ($CuFeS_2$).—Chalcopyrite, a late primary mineral, is locally abundant, but in most of the district it is a rare mineral. It has been noted in the following occurrences: (1) as veins in dolomite breccias along vertical joints (fig. 54), (2) as small tetrahedral crystals on galena, barite, and sphalerite, and (3) as exsolution blebs within sphalerite, galena, and barite. In many places it is associated with marcasite, and surrounded by later calcite. Chalcopyrite is much more abundant in a northwestward trending area in the east-central part of the district than elsewhere (pl. 1). Within this area it was formerly mined as a copper ore. The most important mines are east and southeast of Mineral Point, Wis., in secs. 4 and 5, T. 4 N., R. 3 E., and sec. 32, T. 5 N., R. 3 E. Other copper mines where chalcopyrite is abundant are: (1) the Mount Sterling prospect in the SW¼NE¼ sec. 27, T. 10 N., R. 5 W.; (2) the Plum Creek Copper mine, 5 miles northwest of Wauzeka, Wis., in the SE¼SW¼ sec. 26, T. 8 N., R. 5 W.; (3) south of Linden, Wis., in the center of the W½ sec. 21, T. 5 N., R. 2 E.; (4) near Gratiot, Wis., in the SE¼NW¼ sec. 36, T. 2 N.; R. 3 E.; and (5) in the SE¼SW¼ sec. 8, T. 1 N., R. 5 E. The chalcopyrite contains silver at the copper mine in sec. 36.

Pyrite (FeS_2).—Pyrite is an abundant primary mineral ubiquitously associated with the other ore minerals

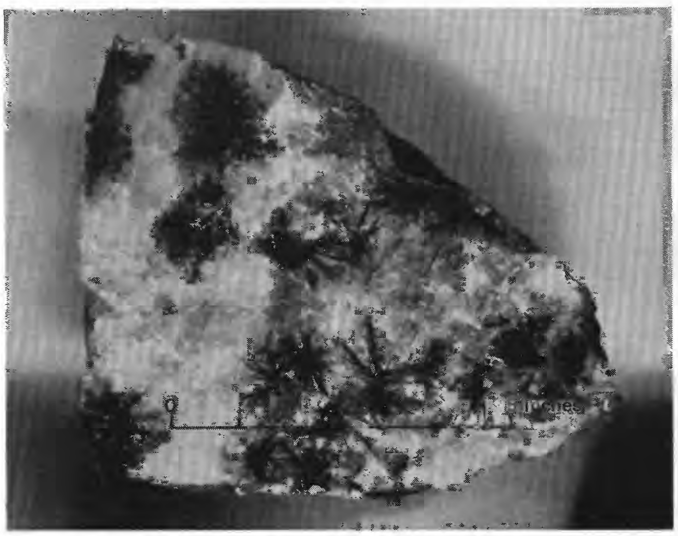


FIGURE 53.—Acicular crystals of millerite in calcite. The millerite, partly altered to violarite and "honessite," is deposited in radiating clusters on the walls of fractures in the Quimbys Mill strata. Calcite later filled the rest of the fracture. Mason mine, Linden, Wis.

FIGURE 54.—Chalcopyrite veinlets in brecciated dolomite. Chalcopyrite (black) veinlets fill fractures in brecciated Galena dolomite, and locally replace the wall rock. Specimen collected from a copper mine at Mineral Point, Wis.

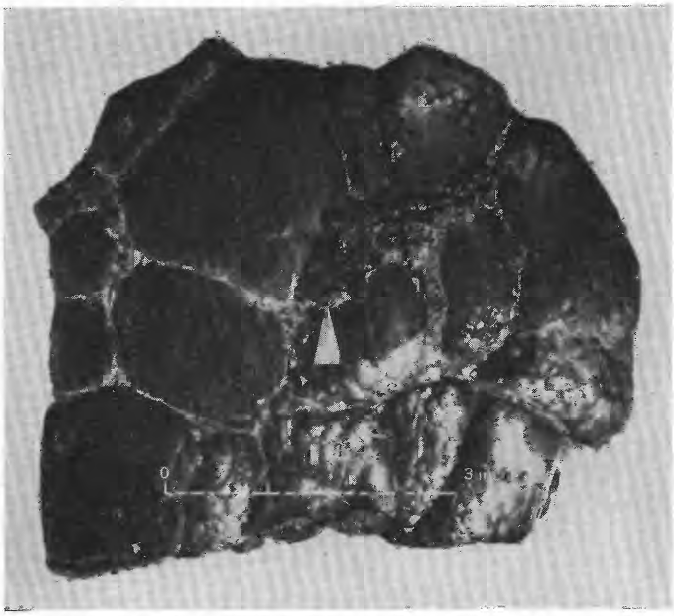


FIGURE 55.—Reniform, crystalline mass of radiating attenuated cubes of pyrite. This specimen illustrates the typical colloform habit of some of the primary vein minerals. The white mark points to a remnant of a crust of crystallized, younger sphalerite deposited upon the pyrite. Defense mine, Mifflin, Wis.

in the district. Pyrite was the first sulfide to be deposited, and its deposition continued for a considerable period, accompanied by the deposition of sphalerite, galena, and marcasite. The early pyrite is as small crystals that replace the wall rock bordering the veins, and as a thin film that coats the country rock of the vein walls (fig. 52). Much of this early pyrite exhibits an octahedral habit, but later crystals generally are cubes in which the edges on many crystals are rounded by vicinal faces. Some of the early pyrite and much of the late pyrite is in reniform masses of radiating crystals composed of greatly attenuated cubes (fig. 55). This colloform habit suggests that colloidal precipitation may have played an important part in the deposition of the ores. Massive replacements of wall rock by pyrite, accompanied by marcasite and to a certain extent sphalerite, are locally abundant in the more intensely mineralized areas, especially along the margins of the ore bodies.

In several parts of the district pyrite has been deposited in large quantities interstitially between the grains of the St. Peter sandstone and the sandy Glenwood shale member of the Platteville formation.

Pyrite is present in essentially every ore deposit of any consequence below the zone of oxidation and in many of the deposits above the water table although here it may be partly altered to limonite. In many places pyrite and its dimorphous associate, marcasite, are the principal minerals of ore bodies that have been mined for the manufacture of sulfuric acid.

Cobaltite(?) (CoAsS) or Safflorite(?) ($CoAs_2$).—A pale-pink sulfate mineral (probably impure erythrite) coats marcasite from the Martin mine south of Benton, Wis., and metallographic examination showed complex intergrowths of a second mineral of somewhat similar optical properties. Such intergrowths have been noted in cobaltious arsenopyrites in other districts. Spectroscopic examination of the sulfide material showed the following elements:

	Percent
Co	0. 06
As	. 20

The analyst was E. Claffy, chemist for the U. S. Geological Survey laboratory, 1946.

This ratio suggests the presence of a mineral of the CoAsS (cobaltite) or $CoAs_2$ (safflorite) type, both isomorphous with marcasite. (Charles Milton, U. S. Geol. Survey, written communication, 1946.)

The arsenic-cobalt mineral very probably exists in small quantities associated with marcasite elsewhere in the district, inasmuch as the pyrite-marcasite concentrates used to manufacture sulfuric acid contain appreciable quantities of arsenic.

Marcasite (FeS_2).—Marcasite is one of the principal minerals of the district. It occurs in a variety of forms and is commonly found in well-formed crystals. Two dimorphous forms may exist: one variety is grayish-green and is as radiating, reniform masses that decompose rapidly upon exposure to air; the second variety is pale, brassy-yellow and has a bright luster. The brassy-yellow variety occurs in crystals and irregular masses that are relatively resistant to oxidation. Possibly this form is actually pyrite psuedomorphous after marcasite. The crystals of marcasite include the cockscomb type, the "Folkstone" type, and simple and complex twinned crystals.

Marcasite has been deposited in conical or cylindrical stalactitic forms in a few places. The individual crystals radiate from the central aperture and are terminated on the external surfaces. Figure 56 shows a specimen obtained from a large vug in the Monroe mine at New Diggings, Wisconsin. The stalactitic forms in this vug project upward from the base of the vug rather than downward from the top, as would normally be expected from the habit. These projecting structures are very similar structurally to the central-tube type of stalactites, but the term "stalactitic form" is used rather than stalagmite, as a stalagmite has no central tube and is developed by drip accumulations from above. The roof of this vug had no stalactites, and the arrangement of upward-projecting stalactitic forms necessitates an entirely different mechanism of origin for these sulfide forms than precipitation by evapora-

FIGURE 56.—Marcasite stalactitic forms from the Monroe mine, New Diggings, Wis. They were deposited as upward projections from the floor of a vug in the center of a large horizontal vein along a bedding-plane fault. Note the central feeder tube and peculiar growth striations.

tion of a descending drop. Apparently, rising gas bubbles in solution, or upward-flowing jets of iron and sulfur bearing water, may have produced these unusual forms.

Marcasite, in comparison with the other sulfides, was deposited over the longest period of time beginning immediately after the first pyrite and continuing to the end of sulfide deposition. The deposition of marcasite in the end stages was accompanied by the precipitation of chalcopyrite and millerite.

Bravoite ($(NiFe)S_2$).—Isometric; H=5.5–6; G=4.62; color, steel gray; luster, metallic; opaque; fracture, conchoidal to uneven; brittle.

Bravoite is found as a rare mineral at the zinc mines in secs. 8 and 18, T. 5 N., R. 2 E., near Linden, Wis. It is intimately associated with violarite, and with "honessite", which is a secondary alteration product of primary millerite. Bravoite is associated with the violarite in small quantities, as a much darker, isotropic, violet-colored mineral, in a zonal relationship suggestive of the zoning observed in bravoite and violarite in other localities. (Charles Milton, U. S. Geological Survey, written communication, 1946.)

Work on the exact determination of this mineral is in progress (Heyl, Milton, Axelrod, 1956) at the Geological Survey's laboratories.

Violarite (Ni_2FeS_4).—Isometric; H=4.5–5.5; G=4.79; color, violet-gray; luster, metallic; brilliant on the fresh surface, but easily tarnished to copper-red or violet-gray; fracture, uneven to subconchoidal; opaque; isotropic.

Violarite is an alteration product of millerite at the Farrey mine in tht NE¼NW¼ sec. 14, T. 1 N., R. 1 E., near Leadmine, Wis. It occurs as pseudomorphs after millerite and replaces chalcopyrite with which it is intimately associated.

Near Linden, Wis., at the mines in secs. 8 and 18, T. 5 N., R. 2 E., primary millerite is associated with primary pyrite, marcasite, galena, sphalerite, and calcite. The millerite has been peripherally altered to violarite (fig. 53), and is accompanied by bravoite and "honessite" (Heyl, Milton, Axelrod, 1956). All stages of this replacement process are present from nearly unaltered millerite with a thin coating of violarite to violarite alone with the millerite completely oxidized.

OXIDES

Cuprite (Cu_2O).—Cuprite has been noted by Cox (Cox, 1909, p. 592) as a secondary oxidation product associated with other secondary copper ores in the center of the NW¼ sec. 36, T. 2 N., R. 3 E., northwest of Gratiot, Wis. Dark red masses are associated with chalcocite, tenorite, malachite and azurite, and smithsonite at the Eberle mine in the NW¼NW¼ sec. 2, T. 6 N., R. 1 E., southeast of Highland, Wis. At this locality very small quantities were observed of brilliant, scarlet, capillary, distorted cubes of the variety known as chalcotrichite.

Tenorite (CuO).—Tenorite is associated with other secondary minerals in areas where copper minerals are abundant. It is particularly abundant at the following localities: the Plum Creek copper mine, in the SE¼ SW¼ sec. 26, T. 8 N., R. 5 W., 5 miles northwest of Wauzeka, Wis.; in secs. 4 and 5, T. 4 N., R. 3 E., and sec. 32, T. 5 N., R. 3 E., just east of Mineral Point, Wis.; and in the SE¼NW¼ sec. 36, T. 2 N., R. 3 E., and the SE¼SW¼ sec. 8, T. 1 N., R. 5 E., both localities near Gratiot, Wis. In many of these places tenorite is in the form of the pitchlike brownish-black variety known as copper pitch.

Hematite (Fe_2O_3).—Hematite occurs in large quantities at the locality known as "Red Rock" southeast of Darlington, Wis., in sec. 17, T. 2 N., R. 4 E., where it forms films between the sand grains, coloring the sandstone bright red. Similar occurrences are present in the vicinity of Hollandale and between Blanchardville and Argyle, Wis. The hematite is attributed by the writers to the alteration of disseminated primary pyrite in the sandstone at these localities. Hematite was found in abundance as an alteration product of iron sulfides in drill holes completed by the U. S. Bureau of Mines in 1947–48 at the Nigger Jim prospect in the NE¼SW¼ sec. 22, T. 4 N., R. 1 E., Iowa County, Wis. The hematite is in partly oxidized ore, and associated with galena, calcite, iron sulfides, and barite. An impure variety of hematite is also present mixed with limonite in the lead-bearing joint deposits where it is the result of the oxidation of iron sulfides (Chamberlin, 1882, p. 394).

Deposits of hematite, a number of which were formerly mined commerically, occur in the north fringe of the zinc-lead district. They are located chiefly in Richland, Vernon, and Crawford Counties, Wis. The ore grades from a hard, dark, compact hematite to red hematitic clays. A list of the more important localities follows (Strong, 1882, p. 49–56): (1) NW¼ sec. 12, T. 10 N., R. 1 W.; (2) SW¼ sec. 7, T. 10 N., R. 1 E.; (3) SE¼ sec. 30, T. 10 N., R. 1 E.; (4) NE¼ sec. 10, T. 11 N., R. 3 W.; (5) NW¼ sec. 18, T. 13 N., R. 2 E.; and (6) at the Ironton mine in the SW¼ sec. 10, T. 12 N., R. 3 E.

Smooth, well-rounded pebbles and cobbles of hard, dark-red to gray hematite were found loose in the soil and clay in ravines southeast of Hazel Green, Wis.; in about the center of the SE¼SW¼ sec. 30, T. 1 N., R. 1 E.; and in the south part of the NW¼NW¼ sec. 32, T. 1 N., R. 1 E., and in two other ravines in the vicinity.

Pyrolusite (MnO_2).—Pyrolusite is reported by Cox (Cox, 1909, p. 592) to have been present in masses 6 to 8 inches in diameter accompanying wad at the copper prospect northwest of Gratiot, Wis., in the SE¼NW¼ sec. 36, T. 2 N., R. 3 E.

Limonite (*hydrous basic ferric oxide*).—This mixture of goethite and other iron oxide minerals is found in large quantities in the oxidized parts of the lead and zinc ore bodies above the water table. Limonite is an alteration product resulting from the decomposition of pyrite and marcasite, and well-formed limonite pseudomorphs of these minerals are common. Limonite is largely impure and earthy in the lead-bearing joint deposits, and colors the clay filling and other crevice material brown or yellow.

Limonite was once mined and shipped in small quantities as an iron ore from the Durango Iron mine, about a mile southwest of Durango, Iowa, on the Chicago & Great Western Railroad. It was derived from the oxidation of pyrite and marcasite in a mineralized joint in which galena was a minor constituent. The ore ranged in grade from 44.55 percent Fe to 57.66 percent iron (Calvin and Bain, 1899, p. 600).

A deposit of limonite, probably an alteration product of pyrite, occurs as stalactitic and botryoidal masses in an area of about 40 acres in the NE¼ sec. 3, T. 12, N., R. 2 E., Richland County, Wis. (Strong, 1882, p. 54), and was prospected by a shaft 36 feet deep.

Psilomelane (*amorphous mixture of various hydrated manganese oxides*).—Psilomelane is commonly found throughout the district in the form of "black ocher", which fills parts of the lead-bearing joints in the zone of oxidation. Small quantities have been observed coating partly oxidized sphalerite in several mines. Apparently the manganese oxide is a derivative of manganese sulfide, alabandite, in sphalerite or is in the form of divalent manganese replacing zinc in the sphalerite itself.

Wad also occurs in some quantity accompanying pyrolusite and copper minerals at the copper prospect northwest of Gratiot, Wis., in the center of the NW¼ sec. 36, T. 2 N., R. 3 E.

An impure earthy variety, brownish black in color, was found in some old lead pits in sec. 11, T. 4 N., R. 1 E., Iowa County, Wis. (Strong, 1877, p. 693).

Abundant black manganese oxide was cut in a hole drilled by the Vinegar Hill Zinc Co. in 1948 in the NW¼SW¼ sec. 21, T. 2 N., R. 1 E., at Meekers Grove, Wis. (DeWitt, O. E., 1948, Geologist, Vinegar Hill Zinc Co., written communication.) This manganese mineral is probably psilomelane, and it was in the Guttenberg member of the Decorah formation, which was altered to soft shale by solution and weathering. The churn drill sample recovered from this 30-foot manganese-bearing zone was found to contain 3.9 percent manganese (Analysis by Vinegar Hill Zinc Co. laboratory furnished through the courtesy of O. E. DeWitt, 1950.) The primary source mineral, from which this secondary psilomelane was formed, is not known, but it may be a primary manganese sulfide, as yet unidentified, or manganese-bearing calcite.

CARBONATES

Calcite ($CaCO_3$).—Calcite is the most abundant gangue mineral of the ore deposits. It is found in a great variety of massive forms, in crystal aggregates and as well developed crystals. Most of the calcite fills the central parts of veins as coarse, milk-white, cleavage masses (fig. 52,), or it lines vugs as crystals up to several inches in size (fig. 63). Calcite is one of the last primary vein minerals to be deposited. The formation of calcite continued after the cessation of deposition of all the other minerals of the ores. Where the veins were refractured, calcite filled late fractures and cemented the fragments of the older vein minerals. Throughout the district calcite exhibits a regular sequence of deposition from early, cloudy calcite, commonly pink, gray, or yellow, to clear, colorless calcite in the final stages of deposition. Small inclusions of sulfides are present only in the early cloudy calcite. A regular paragenetic sequence of at least four crystal habits is noted (fig. 58). Scalenohedral forms predominate in the earlier stages, and rhombohedral forms are most common in the later stages.

Calcite in the form of cave travertine or "onyx" is common as stalactites and banded masses in Crystal Lake Cave, south of Dubuque, Iowa; at the Cave of the Mounds, Blue Mounds, Wis.; at the "onyx mines" in the SW corner of sec. 6, T. 2 N., R. 1 W., and near the center of the S½ sec. 36, T. 3 N., R. 4 W., Grant County, Wis.

Calcite and dolomite are the two major constituents of the abundant calcareous rocks in the area.

Dolomite ($CaMg(CO_3)_2$).—Dolomite, widely introduced and deposited during the early stages of mineralization, is a common constituent of the ore deposits, particularly those in the Prairie du Chien group. Most of the dolomite is white, pale-pink, or salmon-pink. The dolomite forms veins, replaces limestone, and lines vugs as small rhombohedral crystals. All or part of the original limestones, in restricted areas of locally intense mineralization, have been replaced by secondary dolomite. Veins, (fig. 67), and vugs coated and filled with small crystals of dolomite, and masses of replacement dolomite are common in certain mines. At others the secondary dolomite is quite scarce or completely absent.

The dolomite deposited by the ore-bearing solutions is pre-sulfide in age but later than the controlling fractures and the deposition of the silica in the ore deposits.

In addition, the Prairie du Chien group, the Pecatonica member of the Platteville formation, and the Galena dolomite are composed of pre-mineralization, possibly diagenetic, dolomite throughout most of the district, and at places for a considerable distance beyond.

Ankerite ($Ca(Mg,Fe,Mn)(CO_3)_2$).—Ankerite, as pale brown masses and as crystals that fill small vugs, is associated with sphalerite and marcasite in the upper beds of the Galena dolomite. It has been found on the waste piles of an old gold prospect west of Pearl City, Ill. Ankerite was the first vein mineral deposited here, and probably it is equivalent in age to the secondary dolomite found elsewhere in the district.

Smithsonite ($ZnCO_3$).—Smithsonite is the most abundant zinc mineral in the zone of oxidation. Locally, however, it is found along major fractures to a considerable depth below water table. Commonly it is in the form of yellow, brown, or gray, porous, cellular masses. It was mined for zinc from 1859 to 1930, but since then only very small quantities have been mined. The largest production was in the northern part of the district, but other large quantities were produced from the Little Giant mine near Shullsburg, the Sally Waters mine, Empress opencut, and Robson mines near Leadmine, Wis., and the Durango Drybone mine and other mines near Dubuque, Iowa. Some of the types distinguished by the miners are defined below:

"*White bone*"—the best grade—white, solid, and heavy—commonly occurs as flat, scalelike masses with smooth surfaces.

"*Sponge bone*"—the common porous gray and brown cellular variety.

"*Sheet bone*"—massive to porous coatings on rock.

"*Skull bone*"—smooth yellowish plates and fragments.

In some places smithsonite is as colorless or white translucent crystals in vugs in the rock, and thick, white, fibrous coatings with well-terminated crystals, as at the Eberle mine in the NW¼NW¼ sec. 2, T. 6 N., R. 1 E., southeast of Highland, Wis., where it is associated with copper ores. Elsewhere it replaces or forms thick, pearly, crystalline coatings on calcite crystals (fig. 57), the smithsonite being oriented identically with the calcite, as at the Liberty mine in the NE¼ sec. 16, T. 2 N., R. 1 E., at Meekers Grove, Wis.

Large quantities of the massive varieties of exidized zinc ore are actually an intimate mixture of zinc carbonate and the hydrous zinc silicate, hemimorphite. However, smithsonite is, by far, the most abundant mineral of the mixed "drybone" ores.

Aragonite ($CaCO_3$).—Aragonite is present as fine, white, acicular crystals, stalactitic crystallized masses, helectites, and satin spar in Crystal Lake Cave and other

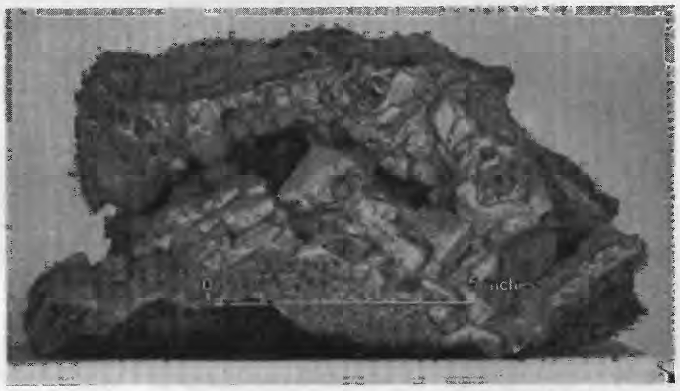


FIGURE 57.—Smithsonite pseudomorphs of rhombohedral calcite crystals. The smithsonite has completely replaced the calcite, first coating the calcite crystal surfaces, and then replacing the central part of the crystal. The rest of the specimen consists of porous spongy smithsonite, Williams mine, Dodgeville, Wis.

caves 5 miles south of Dubuque, Iowa, in secs. 16 and 17, T. 88 N., R. 3 E. It was formed by the evaporation of ground water on the roofs and walls of the caves.

It was noted as a rare mineral in radiating, fibrous masses associated with the lead and zinc ores at the North Unity mine in the E½ of fractional sec. 16, T. 29 N., R. 1 E., in northernmost Illinois. In places, calcite in the ore veins retains radiating pseudomorphs of original aragonite.

Cerussite ($PbCO_3$).—Cerussite is of common occurrence as clear and colorless, white or gray crystals or stellate groups of crystals on galena, just below or more commonly above the water table. Cerussite is a superficial oxidation product of galena and was formed by the action of carbonate meteoric water. It is abundant as a white or yellowish massive crust on weathered galena above water table, and has been found in a massive white form, having the appearance of porcelain, at Waldwick, Wis.

Formerly, cerussite was a minor ore of lead in the district, and commonly was recovered with the more abundant galena.

Malachite ($CuCO_3 \cdot Cu(OH)_2$).—Malachite is an oxidation product of chalcopyrite that is deposited in small quantities at many localities in the district.

Malachite, mixed with the other copper ores, was mined near Mount Sterling, Wauzeka, Linden, Mineral Point, and Gratiot, Wis., during the nineteenth century.

Small fibrous crystal tufts and globular masses of malachite accompany other copper ores at the Eberle mine southeast of Highland, Wis., in the NW¼NW¼ sec. 2, and on the Steppler farm at Centreville, Wis., in the SE¼NE¼ sec. 7, T. 6 N., R. 1 E. It is also found in small quantities in many other parts of the district, especially along the northern and eastern fringes.

Azurite ($2CuCO_3 \cdot Cu(OH)_2$).—Azurite, like malachite, was formerly mined with other copper ores in the vicinities of Mount Sterling, Wauzeka, Mineral Point, and Gratiot, Wis.

It is in the form of well-formed small crystals and crystalline coatings on rocks and other copper minerals at the Eberle mine southeast of Highland, Wis., and at the old copper mines near Mineral Point and Gratiot, Wis.

Like malachite, azurite is a surface oxidation product formed from the original chalcopyrite.

Aurichalcite ($2(Zn, Cu)CO_3 \cdot 3(Zn, Cu)\ (OH)_2$).—Monoclinic; H=2; G=3.6; color, pale-green to blue; luster, pearly; streak, pale-greenish or bluish; translucent; in acicular crystals forming drusy incrustations.

This double basic carbonate of zinc and copper is found in small quantities at two places in the district. As small, pale-blue, silky tufts in cavities, aurichalcite is associated with partly oxidized copper and zinc ores at the Eberle mine in the NW¼NW¼ sec. 2, T. 6 N., R. 2 E., southeast of Highland, Wis. This mineral is present as small, bluish-green, radiating films along calcite cleavage planes associated with chalcopyrite and traces of sphalerite at an old dump in the southeast corner of the SE¼SW¼ sec. 12, T. 1 N., R. 2 E., one mile east of Leadmine, Wis.

Similar to azurite and malachite, it is a surface oxidation product of sphalerite and chalcopyrite.

Hydrozincite ($2ZnCO_3 \cdot 3Zn(OH)_2$).—Amorphous; H=2–2.5; G=3.69; color, white, gray, or yellow; streak, shining; luster, dull; earthy, reniform, fibrous.

Hydrozincite occurs in small quantities at several localities as a surface oxidation product associated with smithsonite and hemimorphite.

It is reported by Hall and Whitney (1862, p. 220) and Strong (1877, p. 694) to be present as finely crystalline, white, fibrous incrustations on smithsonite at Linden and Mineral Point, Wis.; white, compact, platy crusts of hydrozincite coat mixed smithsonite and hemimorphite, and calcite, at a prospect in the SW¼ sec. 30, T. 3 N., R. 2 W., 1½ miles east of Tennyson, Wis.

SILICATES

Quartz (SiO_2).—Quartz is represented in the district by four varieties: drusy, crystallized quartz; chert or 'flint"; agate or chalcedony; and an impure earthy variety resembling "cotton rock" (Fowler, 1935, p. 106–163) or tripoli.

Quartz is present as widespread sedimentary cherts generally in nodular bands in the Prairie du Chien group, Galena dolomite and also as silica deposited in the earliest stage of mineralization within the ore deposits.

Older chert is a characteristic constituent of the lower part of the Galena dolomite, where it is possibly an original diagenetic mineral formed from a silica gel that replaced the sediments before induration. The chert is deposited as beds and bands of nodules at vertical intervals in the Prosser member. Individual chert bands are traceable throughout large parts of the district. Similar bedded cherts are present in the Prairie du Chien group and the dolomite of Silurian age.

Secondary quartz is particularly abundant in the ore deposits of the Prairie du Chien group. Within the mineralized areas a considerable part of the dolomite rock was replaced by this younger silica, mostly in the form of chert and jasperoid.[20] Abundant drusy quartz

[20] The term "jasperoid" is used for silica in the form of chalcedony or fine-grained quartz aggregates approaching chert in appearance, deposited in veins, coating the walls of cavities, and replacing the carbonate wall rocks of the ore deposits.

lines cavities, accompanying the jasperoid. Small veinlets of drusy comb quartz crystals are not uncommon. These veinlets are generally double-banded, and the quartz crystal terminations along both sides face the center of the vein. In the Prairie du Chien and the overlying beds, this secondary silica was the first mineral deposited by the ore-bearing solutions.

Younger chert and jasperoid are present in the zinc deposits in the Platteville, Decorah, and Galena, but they are rare or absent in the overlying gash-vein lead deposits. The silica is most commonly in the form of irregular chert nodules, jasperoid, or partial to complete replacement of the rock without essentially changing its appearance. This later silica has replaced some of the rock adjacent to the fractures, and has formed white, porous, chalky "cotton rock". Crystallized quartz is very rare, and the degree of silicification in these zinc deposits is quite varied. At some mines, such as the Hoskins mine at New Diggings, Wis., nearly all of the limestone within the ore body has been completely silicified; in other mines the silification is present as local patches along the principal fractures, and in many mines it is absent or of rare occurrence.

Quartz in the form of well-rounded sand grains is the principal constituent of the St. Peter sandstone and the underlying Upper Cambrian formations. Beneath certain ore deposits, and along faults and fractures, these loosely cemented sandstones have been impregnated with secondary silica in the form of crystal overgrowths on the sedimentary quartz sand grains. This secondary silica has indurated the sandstone to a quartzite.

Hemimorphite ($Zn_2SiO_4 \cdot H_2O$).—This mineral is intimately mixed with smithsonite, the minerals together forming the typical "drybone" of the district.

Hemimorphite is present in an adit in the SW¼ sec. 30, T. 3 N., R. 2 W., 1½ miles east of Tennyson, Wis., accompanying smithsonite and hydrozincite; at the Ida Blende mine near Benton; and in smaller quantities at Dodgeville and Mifflin, Wis. It is common in zinc deposits above the zone of oxidation elsewhere in the district.

It was reported by Strong (1877, p. 693) as a rare mineral at Mineral Point, Wis., as druses of colorless brittle crystals on smithsonite. Crystals of hemimorphite were noted also near Dubuque, Iowa, by C. H. Behre, Jr. (C. E. Brown, written communication, 1957) at the Lockey Range (pl. 4).

Muscovite, variety sericite ($(H,K)\,AlSiO_4$).—Sericite is common at the Demby-Weist mine in the SW¼ sec. 21, T. 7 N., R. 4 E., Iowa County, Wis.

It is deposited there as pearly white flakes, scales, and silky tufts in small cavities in silicified dolomite and sandstone of the Jordan sandstone member of the Trempealeau formation of Cambrian age. The rocks have been silicified and sericitized along the northeast side of the Demby-Weist mineralized fractures. Probably the sericite and the silica were deposited during the early stages of mineralization.

The determination of the sericite was made by C. S. Ross, mineralogist, U. S. Geological Survey (written communication to A. V. Heyl, 1948).

Sauconite ($(Zn_{1.54}Mg_{.15}Al_{.78}Fe_{.23})\ (Al_{.61}Si_{3.39})\ O_{10}(OH)_2Ca/2_{.18}K_{.02}$).—Amorphous; H=1; G=2.24–2.30; color, drab to light brown; luster, greasy, waxy; optically (−); indices of refraction, α 1.570, γ 1.605.

This zinc clay mineral, analogous to the magnesium clay mineral saponite, has been found in the Liberty mine at Meekers Grove, Wis., in the NE¼NE¼ sec. 16, T. 2 N., R. 1 E. It is restricted to the upper stopes of the mine, in the zone of incipient oxidation within the area of the fluctuating water table. Sauconite is in the form of a drab or pale brown, soft tallow-clay filling vugs in the centers of veins of sphalerite and marcasite. The sphalerite in the veins is very slightly oxidized and has only a thin film of smithsonite upon it. Apparently, the zinc in the clay came not only from the oxidation of the enclosing ore vein, but to a large extent was carried down with the other constituents and redeposited at the water table as sauconite.

Clarence S. Ross (1946, p. 411–424) gives a full description of the chemical analyses and chemical formulas of sauconite from this locality in comparison with other known occurrences of the mineral.

Analyses of two samples of this material from the Liberty mine are given below:

	A	B		A	B
SiO_2	38.59	38.70	Na_2O	0.01	0.43
Al_2O_3	13.36	16.29	K_2O	.18	.32
Fe_2O_3	3.41	3.91	CuO	------	------
MgO	1.18	1.62	TiO_2	.31	.30
MnO	------	.06	H_2O-	10.39	7.50
ZnO	23.50	22.48	H_2O+	8.05	8.38
CaO	.94	Tr.			
				99.92	99.99

NOTE:

Sample A, M. W. Carron, analyst, U. S. Geological Survey.
Sample B, S. H. Cress, analyst, U. S. Geological Survey.

Glauconite, essentially a hydrous silicate of iron and potassium.—Glauconite is abundant as a bedded sedimentary mineral in certain greenish shaly and sandy beds of the Prairie du Chien group, and also as deep-green coatings and stains; resembling malachite, at several of the mineral deposits in this group.

Sedimentary glauconitic beds occur throughout the Prairie du Chien group and may be found in many of the outcrops of this formation throughout the district.

A deep-green mineral, probably celadonite, whose physical and optical properties are similar to those of glauconite, is associated with galena, sphalerite, pyrite, and jasperoid, possibly formed by solution and redeposition of the sedimentary glauconite by the ore solutions at the Ohlerking lead mines west of Highland, Wis., and the quarry 3 miles southeast of Bridgeport, Wis., along Wisconsin State Highway 35.

Zincian montmorillonite.—Tallow-clay similar to true sauconite is found in the Helena-Roachdale mine located in the NE¼SW¼ sec. 7, T. 1 N., R. 2 E., 2 miles east of Leadmine, Wis. This material is identical in appearance and occurrence to sauconite, but study by Ross (1946, p. 411–424) proved it to be zincian montmorillonite. An analysis of this material follows:[21]

SiO_2	40. 62	Na_2O	0. 88
Al_2O_3	12. 79	K_2O	. 10
Fe_2O_3	9. 73	TiO_2	. 66
FeO	----	P_2O_5	----
MgO	1. 67	H_2O-	8. 92
MnO	. 04	H_2O+	11. 59
ZnO	3. 82		
CaO	. 10		99. 92

From this analysis Ross gives the following formula:

$$(Al_{1.28}Fe'''_{.58}Mg_{.20}Zn_{.22})\ (Al_{.76}Si_{3.24})O_{10}(OH)_2$$
$$(Na_{.12}Ca/2_{.2}K_{.01})$$

PHOSPHATES AND ARSENATES

Pyromorphite ($Pb_5Cl(PO_4)_3$).—Hexagonal; H= 3.5–4; G = 6.9–7; color, pale-green, yellow, white and gray; fracture, conchoidal; luster, resinous; streak, white, greenish-gray to gray; brittle; subtranslucent to nearly opaque.

Minute pale-green, yellow, or brown, hexagonal, barrel-shaped crystals of pyromorphite were noted on pyrite and chalcopyrite at the Eberle mine, southeast of Highland, Wis.

Pyromorphite is present as white to gray, hexagonal crystals coating limonite pseudomorphs after calcite on a specimen from the Wisconsin district now in the museum of the Wisconsin Institute of Technology. The exact source of the specimen is unknown, but its characteristics indicate that it came from the oxidized zone of either a zinc or lead deposit.

Erythrite ($Co_3(AsO_4)_2\cdot 8H_2O$).—Monoclinic; H= 1.5–2.5; G = 2.95; color, shades of pink and red; cleavage, *b* perfect, *a* and *m* (101) distinct; luster, earthy to pearly; translucent to opaque.

At the Martin mine half a mile south of Benton, Wis., partly altered marcasite was coated with pale pink crusts of an impure mixture that was probably erythrite and intermixed melanterite. Chemical tests made by the U. S. Geological Survey (Milton, Charles, written communication, 1946) were inconclusive inasmuch as very little of the pink material existed, and this small quantity was difficult to separate from the other substances. However, a microscopic study of the underlying marcasite showed complex intergrowths of a second mineral, possibly cobaltite or smaltite, containing cobalt and arsenic, suggesting that the pinkish crusts probably were in part erythrite.

[21] Sample C, J. G. Fairchild, analyst; U. S. Geological Survey.

SULFATES

Barite ($BaSO_4$).—Barite in white, platy, tabular masses is locally a common to abundant gangue mineral of the ore deposits. Crystals are rare. It is primary, and in part early, but most of it is late in the sequence of ore deposition. Barite is associated with the other ore minerals. Commonly barite fills the central parts of the veins; however, it forms two parallel bands near the center of some veins, the still-younger calcite filling the remaining central apertures. Some of the barite is fine-grained with a radiating, concentrically banded, reinform habit that suggests colloidal deposition.

The greatest concentration of barite is found in the central part of the district, where it is abundant in most of the ore deposits. Small tonnages of barite were mined from this area in the years 1919 to 1930, inclusive. Beyond this central area of barite concentration, toward the east, south, and west, the mineral diminishes in quantity until it is uncommon or absent near the district margins.

Anglesite ($PbSO_4$).—Anglesite is a rare mineral in the district. It is reported by Chamberlin (1882, p. 395) as small crystals in cavities in galena where it was protected from the carbonated waters that normally alter it to cerussite.

The sulfate of lead is reported by Hall and Whitney (1862, p. 213–214) to be present in a banded, massive form surrounding partly altered crystals of galena at Durango, Iowa, and as small crystals lining cavities in galena at Mineral Point, Wis., and Mineral Creek north of Waukon, Iowa.

Gypsum ($CaSO_4\cdot 2H_2O$).—Gypsum occurs in small quantities in cavities, caves, and old mine workings where it forms from calcium-bearing surface solutions reacting with oxidizing sulfides. It was noted in the form of small acicular crystals in the old stopes of the Galena Level mine, 2 miles northwest of Shullsburg, Wis., and at the Graham mine, in the center of sec. 32, T. 29 N., R. 1 E., 3 miles north of Galena, Ill.

Acicular crystals, 5 or 6 inches in length and one-fourth inch or less in diameter, were found by A. G. Leonard (1897, p. 36) on the clay floors of the caves 5 miles south of Dubuque, Iowa, in secs. 16 and 17, T. 88 N., R. 3 E.

Epsomite ($MgSO_4\cdot 7H_2O$).—Silky white tufts of this mineral are found with other sulfates above the water levels in the drier parts of many of the old mines where it formed from the magnesium of the dolomitic limestone and the sulfate radical derived from decomposing pyrite and marcasite. It is generally accompanied by melanterite, copiapite, gypsum, and goslarite. It was in considerable abundance at the Helena-Roachdale and Galena Level mines between Benton and Shullsburg, Wis.

Goslarite ($ZnSO_4 \cdot 7H_2O$).—Goslarite has been noted as powdery white tufts on the drier walls and floors of old mine stopes. It is an oxidation product of sphalerite.

Melanterite ($FeSO_4 \cdot 7H_2O$).—Melanterite accompanies other sulfates and is common wherever marcasite or pyrite are decomposing, mainly in the drier parts of old stopes but also on the more protected parts of old mine dumps. It is as white or pale-greenish-white masses and crusts on weathered marcasite.

Beautiful, pale-bluish-green, curved, coarsely fibrous masses of melanterite have been deposited in the upper stopes of the Galena Level mine, 2 miles northwest of Shullsburg, Wis.

Copiapite ($Fe_2(FeOH)_2(SO_4)_5 \cdot 17H_2O$).—The bright-yellow iron sulfate, copiapite, forms with melanterite from the decomposition of marcasite and pyrite. It is of common occurrence accompanying the other sulfate minerals in old mine stopes and protected parts of the mine dumps.

"Honessite" hydrous basic nickel-iron sulfate.—A new probable species, data as yet incomplete (1957); color yellow, orange-yellow, yellow-green to bright-green; H=1 to 2; mean refractive index is 1.615.

This probable new mineral (Heyl, Milton, Axelrod, 1956) is an associate of millerite and violarite and has been formed as an alteration product of these minerals. It is found at nearly all the zinc mines in secs. 8 and 18, T. 5 N., R. 2 E., near Linden, Wis. (fig. 53).

A report in press[22] describes results of the study of "honessite" to date (1957):

"Alteration, probably by weathering, partial or complete, of the radial aggregates of millerite needles and the secondary violarite and bravoite has occurred. The replacing substance varies in color from bright green, through yellow to reddish brown. This variation is thought to correspond to varying degrees of oxidation of the iron present.

"Microscopic examination of the pseudomorphs after millerite show the material to be extremely fine grained and not uniform. There is an obscurely fibrous structure, with positive elongation with extinction at about 12°. Very few areas even under high magnification are clear from turbidity, and these are too small for conoscopic study. The mean refractive indices are 1.615, and the double refraction is very low. There appear to be no sensible differences between the vari-colored particles optically, except for color.

"In an attempt to clarify the crystalline structure of the honessite, electron micrographs were prepared through the kindness of Edward Dwornik of the Geological Survey, but no indication of crystal form was seen.

"X-ray diffraction patterns from numerous samples of the material prepared by J. M. Axelrod of the Geological Survey, had broad lines not referable to any known mineral. Besides sharp lines referable to known materials present such as calcite, cerussite and millerite, there were:

d	*I*	
8.7	10	001
4.33	2	002
2.67	2	$h_1k_1^0$
1.542	2	$h_2k_2^0$

"R. C. Erd has noted that a synthetic hydrous zinc hydroxide gives an x-ray diffraction pattern very similar to that of "honessite" (oral communication).

"Figure 6–27C in Klug and Alexander's *X-Ray Diffraction Procedures*, the x-ray diffraction pattern of "anodic nickel hydroxide", is also very similar to honessite. If this material consists partly of trivalent nickel, "honessite" may be isomorphous with it with trivalent iron replacing trivalent nickel.

"K. J. Murata of the Geological Survey made a spectrographic analysis of the green material and found Ni, Ca, Fe, Co and minor Pb, Mg, Mn, Si, Zn?.

"Chemical analyses were subsequently made on three different samples isolated from the same source material.

	A	*B*	*C*
NiO	42. 6	33. 4	35. 3
CoO	3. 6	3. 2	1. 8
FeO	2. 4	N. D.	N. D.
Fe_2O_3	10. 5	*13. 7	*15. 8
CaO	2. 7	10. 5	2. 5
SO_3	10. 8	10. 7	8. 6
H_2O-	4. 7	5. 1	7. 1
H_2O+	19. 7	19. 5	19. 7
Insol. + SiO_2	. 9	3. 4	2. 2
CO_2	absent	N. D.	N. D.
S (sulfide)	absent	absent	absent
	97. 9	99. 5	93. 0

*Total iron calculated as Fe_2O_3.
N. D.—Not determined.

A. Robert Meyrowitz, U. S. Geological Survey, Analyst.
B, C. Charles A. Kinser, U. S. Geological Survey, Analyst.

"Obviously, the three analyses are by no means conclusive as to the composition of the material. Considering the nature of the material, and the small quantities analyzed (15 mg.), however, there is more or less agreement. At any rate it appears that the material is essentially a hydrous basic sulfate of nickel and ferric iron, with CaO as a major or minor constituent. Beyond this it would be profitless to interpret the analyses in terms of a formula . . . . except that it consists essentially of a single substance, or, possibly, of a series connected by FeO-Fe_2O_3 variation, as in the frondelite-rockbridgeite series".

ELEMENTS PRESENT IN SMALL QUANTITIES IN THE ORES

Spectroscopic analyses of the mill products at the Vinegar Hill Zinc Company's custom mill at Cuba City showed definite amounts of certain uncommon elements, including cadmium, cobalt, nickel, germanium, molybdenum, zirconium, and vanadium.[23] Apparently all

[22] Heyl, A. V., Milton, Charles, Axelrod, C. E. Nickel minerals near Linden, Iowa County, Wis. (In press, Am. Mineralogist.)

[23] Spectroscopic assays by J. C. Rabbitt, U. S. Geological Survey, March 1943.

these elements are either in rare minerals or as impurities in the ore minerals. Arsenic, manganese, and silver also are known to be present by analyses of ores from the district.

Since the spectroscopic studies were completed, minerals that contain some of these elements have been identified as shown below:

Element	*Minerals in which it occurs*
cadmium	greenockite, sphalerite
arsenic, cobalt	pyrite and marcasite containing cobaltite (?) or smaltite (?)
nickel	millerite, violarite, bravoite, honessite
silver	galena (argentite?), chalcopyrite
manganese	psilomelane, sphalerite, calcite

Cadmium is present as an impurity in the sphalerite. Assays of cadmium in the ores are given in percent as follows:

Sample No.[1]	Mine	Zinc	Iron	Cadmium	Approx. cadmium in calculated ZnS
1	Gray	31 37	12.53	0.14	0.29
2	Gray	5.68	3.10	.10	1.17
3	Gray	31.52	12.43	.14	.29
4	Liberty	12 90		.05	.25

[1] Sample 1, assayed for the Tri-State Zinc Co., Galena, Ill., Assayer not known, 1945. Samples 2 and 3, assayed by U. S. Bureau of Mines, Rolla, Mo., 1945. Sample 4, assayed by Vinegar Hill Zinc Co. laboratory at Cuba City, Wis. Furnished through the courtesy of E. G. Deutman, General Superintendent, 1950.

The sphalerite in sample no. 2 was coated with greenockite and therefore was enriched. Probably the other samples approximately represent the normal cadmium content of the ores and sphalerite in the district, which is usually lower than in the sphalerite of the Tri-State district of Missouri, Oklahoma, and Kansas, where the average is about 0.35 percent cadmium in the sphalerite (Budgen, 1924, p. 5).

Formerly, small quantities of arsenic in the ores interfered with the manufacture of sulfuric acid in the district. The arsenic is believed to be in the form of cobaltite or smaltite as intergrowths with marcasite. Apparently more of this arsenic-cobalt mineral is present in the ores of certain mines than in others. Listed below are analyses of typical gravity mill concentrates from several mines, showing the percent of arsenic in the ores.[24]

Mine	Approx. Zinc (percent)	Approx. Iron (percent)	Arsenic in concentrate (percent)	Approx. arsenic in calculated FeS_2 (percent)
Badger	39	15	0.070	0.217
James	25	26	.030	.054
Birkett	36	16	.018	.05
Mullen	32	19	.018	.045
Ida Blende	36	15	.0076	.024
High Top	35	17	.0053	.0145

[24] Analyses by Vinegar Hill Zinc Co. laboratory at Cuba City, Wis., furnished by E. G. Deutman, General Superintendent, 1950.

These analyses show notable quantities of arsenic in the iron sulfides at the first four mines listed. Other places where the iron sulfides are known to contain arsenic are the McKinley mine at Dodgeville, the Rule mine north of Linden, and the Jefferson mine north of Hazel Green, all in Wisconsin.

Sixteen ounces of silver was recovered from 37 tons of chalcopyrite ore from the Gratiot copper mine in 1914 (U. S. Geol. Survey, 1914, pt. 1, p. 123). The silver apparently was found in the chalcopyrite, and this is the most notable occurrence of silver in the district.

Silver is in the galena in small but measurable amounts. Reliable assays range from 0.12 to nearly 2 ounces per ton. It is apparently also in pyrite and marcasite in at least a few localities.

From several localities lead concentrates assayed for silver and gold produced the following results.[25]

Sample No.	Silver (troy oz. per 2,000 lb.)	Gold
1	0.12	Tr.
2	.38	Tr.
3	.32	Tr.
4	.72	Tr.
5	.14	Tr.
6	.94	Tr.
7	.42	Tr.
8	1.74	Tr.
9	.20	Tr.

Sample No.	*Description*	*Locality*
1	Galena, jig concentrate, zinc mine.	Liberty mine, Meekers Grove, Wis.
2	Galena, from a gash-vein, lead mine, in Galena dolomite.	Joe Stegan mine, 3 miles north of Mineral Point, Wis.
3	Galena, from Decorah formation Zinc mine.	New Hoskins mine, 1 mile east of Leadmine, Wis.
4	Galena and a little dolomite from a north-striking vertical vein in Galena dolomite, outcrop.	Center NW¼SE¼ sec. 31, T. 1 N., R. 1 E., at Hazel Green, Wis.
5	Galena, from Prairie du Chien group, quarry.	1 mile west of Highland, Wis.
6	Galena, little sphalerite, shale, and dolomite (from Platteville formation), zinc mine.	Dodgeville mine, Dodgeville, Wis.
7	Galena, from top of pitch-and-flat zinc ore body.	North lead shaft, Graham-Ginte mine, 3 miles north of Galena, Ill.
8	Galena, little sphalerite, and calcite, zinc mine.	James mine, Shullsburg, Wis.
9	Galena, zinc mine	Piquette-Trego mine, Platteville, Wis.

Assays made in the nineteenth century, for silver in galena from some localities, gave even higher results; but the veracity of these assays cannot be checked. These assays follow:[26]

[25] Assayer, Ledoux and Co., Inc., New York, January 5, 1948.

[26] Samples 1, 2, 3, Assayer, Chandler and Kimball; from Hall and Whitney (1862, p. 199).
Sample 4, Assayer unknown; from Leonard (1896, p. 56).
Sample 5, Assayer unknown; from Jenney (1893, p. 21).

Sample No.	Locality	Silver (troy oz. per 2,000-lb. ton)
1	Rockville, Wis	0.125
2	Mineral Point, Wis	3.000
3	Black Jack mine, Galena, Ill	.070
4	Lansing mine, Lansing, Iowa	4.000
5	Lansing mine, Lansing, Iowa	2.600

Samples of mineralized material from the Staderman gold prospect at Eleroy, Ill. (Hershey, 1899, p. 240–244) were assayed for gold and silver by the U. S. Bureau of Mines with the following results:[27]

Sample	Description	Gold (troy oz. per ton)	Silver (troy oz. per ton)
A	Marcasite and sphalerite	0.0025	0.27
B	Marcasite, pyrite, collophane, and gypsum in basal Maquoketa shale	.0025	.15
C	Marcasite and galena	.005	.56

These samples show a small but significant quantity of silver, and a trace of gold so small as to be questionable.

A rock sample of the material containing nickel minerals was selected from the dump at the Mason mine near Linden, Wis., in the SE¼SW¼ sec. 8, T. 5 N., R. 2 E., and upon analysis contained 0.22 percent nickel. (Analysis by W. W. Brannock, U. S. Geological Survey, May 23, 1947.)

The nickel is in the form of millerite, violarite, and honessite associated with galena, sphalerite, pyrite, and marcasite in the beds of the Quimbys Mill member of the Platteville formation.

PARAGENESIS

The minerals in the ore deposits occur in a nearly unrepetitious paragenetic sequence. Many of the ores have been deposited in simple banded veins with the early minerals near the walls; but where a vein was reopened along the center or along the walls during deposition, the order of deposition, though apparently complex, is still not repeated. Where the minerals have replaced or impregnated the wall rock or formed replacement veins, the same paragenetic sequence of deposition is present as in the fissure veins themselves.

PREMINERALIZATION RELATIONS

The bedded nodular cherts of the Prairie du Chein group, Galena dolomite, and strata of Silurian age are apparently the result of diagenetic replacement.

Within the district a large part of the carbonate strata consists of dolomite. This dolomite (exclusive of that deposited with the ores) is of pre-mineral age and may possibly be an original primary chemical sediment, but it is more probably a replacement of the calcareous sediments on the sea floor by diagenesis previous to induration. Replacement relations of the limestone by the dolomite are abundantly seen in the rocks, and a few islandlike areas of unreplaced limestone in the normally dolomitic Galena at Leadmine, and west of Fairplay, Wis., have been noted.

In the region along the axis of the Wisconsin arch, all the calcareous beds of the Decorah and Platteville formations have been dolomitized (Chamberlin, 1883, p. 165), which suggests that some of the older dolomite replaced the limestones after induration and is related to the rise of the Wisconsin arch. Although this Decorah and Platteville dolomitization is of the wide extent that is commonly regarded as diagenetic, it is notably more complete along the axis of the Wisconsin arch, and less so within the areas of mineralization. Also, in small areas, substantial parts of these beds (except for the Pecatonica member) are limestone rather than dolomite, suggesting that these areas are "islands" of unreplaced limestone that are retained where protected by geologic structure. In the broad area over the arch, dolomite of the Decorah and Platteville is identical in appearance to that related to mineralization farther west.

Mineralization in the district appears to have taken place near the end of the period of tectonic deformation that produced the folds and faults. The earlier stages of deformation cause the formation of reverse faults, bedding-plane faults, and joints, which are the fractures that control the ore bodies (figs. 44, 45). Later, but still before the beginning of mineralization, shear faults were developed that displaced the earlier fractures, as in the Liberty mine at Meekers Grove, Wis. (fig. 23).

The general sequence of tectonic events, before and during mineralization, and their relation to the paragenetic sequence of deposition of the ore minerals, is shown in figure 58.

RELATIONS DURING ORE DEPOSITION

Quartz stage.—Crystalline and cryptocrystalline silica was deposited as the earliest mineral related to mineralization. Several varieties of silica replaced the rock as chert, jasperoid, or "cotton rock" or were deposited as crystalline quartz in drusy open vugs or small veins. The crystalline quartz is restricted to the localities that are most intensely silicified, but the other varieties are far more widespread and appear to indicate a lesser degree of silicification.

The most intense silicification, hence the largest amount of crystalline quartz, is in the deposits in the Prairie du Chien group.

Similar silicification, though less intense, is found in the overlying beds of the Platteville, Decorah, and Galena and is commonly restricted to the ore bodies

[27] Fire assays by U. S. Bureau of Mines, Rolla, Mo., 1944.

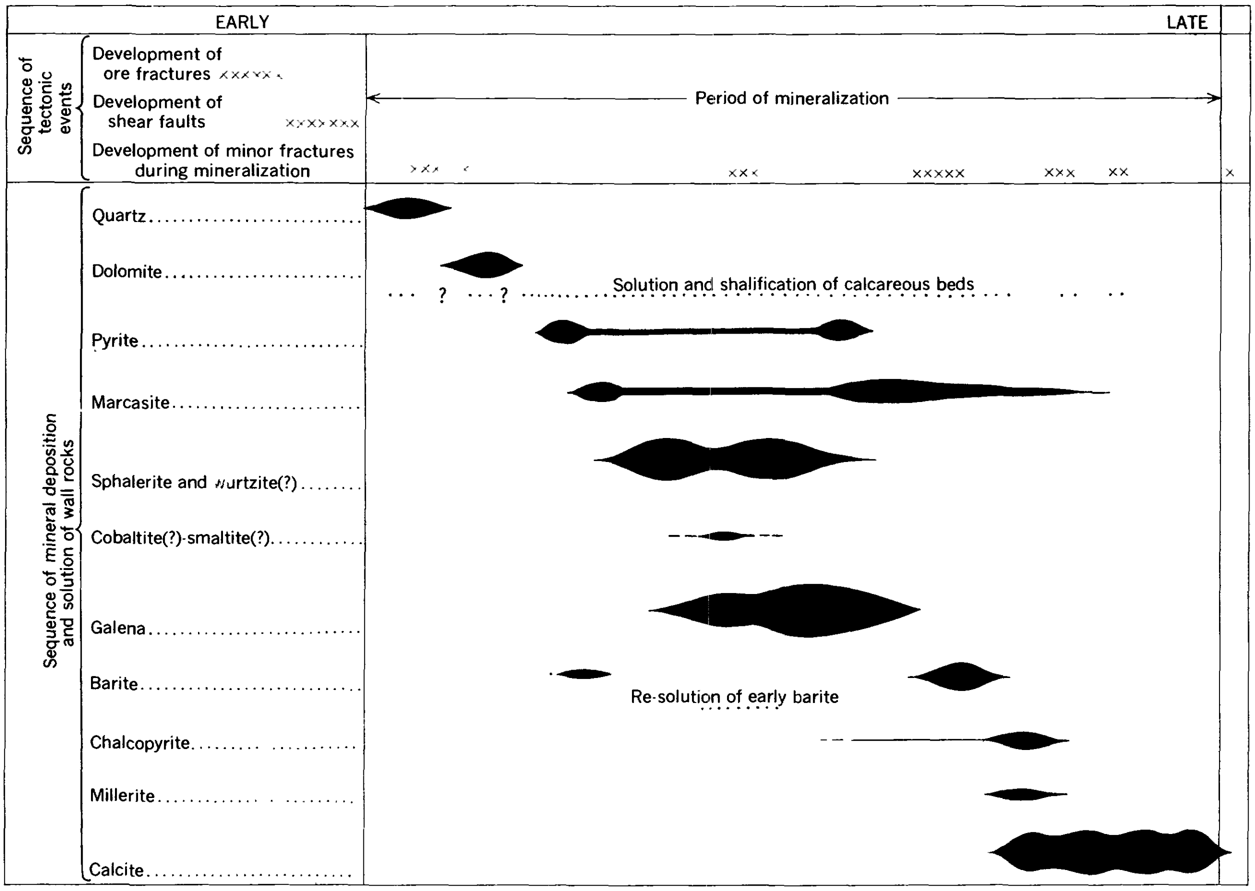


FIGURE 58.—*Sequence of tectonic events and deposition of primary minerals.*

themselves. In all of those beds, the chert, jasperoid, and "cotton rock" deposits of silica are predominant. Bands or areas of limestone and pre-ore dolomite have been replaced by the silica within or bordering the ore bodies. Silica is particularly abundant in the vicinity of the principal fractures within the ore bodies. Single beds near the fractures change fairly abruptly from the original carbonate rock to the silicified zone. In places sharp, cross-cutting boundaries are observed, but in many others the change is a gradational replacement of the limestone by the silica.

Silicified rock is widespread in the pitch and flat ore bodies, but rare in the overlying gash-vein deposits. However, secondary silica is absent in some pitch-and-flat ore bodies, although in others a large part of the calcareous rock within the deposits is silicified.

After silicification but before the deposition of the later minerals, renewed deformation caused fracturing that has been observed at several localities.

Dolomite stage.—Deposition of dolomite was the second stage of mineralization (fig. 58). Dolomite replaced the limestones of the Platteville and Decorah formations and was deposited as small, pale-pink crystals lining vugs, or as crosscutting veins of a fine-grained, pink aggregate filling fractures (fig. 67). These veins cut the earlier bedded dolomites of the Prairie du Chien group and Galena dolomite, and, everywhere seen, pink dolomite is older than the first sulfides.

Like the silica, the pink dolomite is restricted to the ore deposits themselves, or to alteration zones about them, and ranges in abundance from complete limestone replacement within an ore body, through minor local dolomitized areas or veins, to complete absence in a number of deposits. This younger dolomite is most abundant in the ore deposits in the Prairie du Chien group, less so in the overlying pitch and flat zinc deposits, and quite rare or absent in the gash-vein lead deposits.

Solution stage.—Limestone and, to a lesser extent, dolomite wall rocks within and surrounding the ore bodies have been partly dissolved and thinned by the ore-bearing solutions forming shaly residues. The dolomites more commonly have been attacked and partly dissolved at the individual grain boundaries or have had only their more calcareous parts removed. The resulting altered rocks are porous, vuggy, or "sanded" (Lovering, 1949, p. 27), and are very permeable, and form a favorable host rock for the ores.

Solution of the wall-rock limestome and dolomite probably began just before the start of sulfide mineralization (fig. 58), but at least a little solution-thinning may have occurred earlier during the period of quartz and dolomite deposition. Where silicified, the wall rocks have been very slightly dissolved and thinned, but many of them so completely preserve the appearance, texture, and thickness of the sublithographic limestones they have replaced that it is difficult to usually distinguish between them in outcrops. Similarly, the dolomitized limestones have not been as greatly altered by solution as adjacent limestones of the same beds. Sanded dolomite is abundant in the dolomitized rocks that are thinned, indicating that much of the solution that did occur in these rocks took place after the rocks were dolomitized.

The main period of solution of the wall rocks probably started after dolomitization and before the first sulfide, pyrite, was deposited, and continued during sulfide deposition. The early pyrite lines solution vugs and fills interstices in dolomitized wall rocks already sanded by the solution of their bonding cements. All the primary sulfides, as well as barite and some of the earlier crystallized calcite, were deposited on wall rocks that were later partly dissolved by the ore-bearing solutions. The solution process apparently continued all through the period of sulfide deposition and ceased simultaneously as the last marcasite was deposited (fig. 58).

When calcite deposition started, the solution of the wall rocks became spasmodic and local, but continued at intervals to the end of the second of the four substages of calcite deposition. When calcite was being deposited, solution ceased for a time, but periodically small quantities of marcasite, chalcopyrite, and millerite were deposited and solution-corrosion was renewed, which etched the calcite already deposited and locally dissolved the wall rock beneath the calcite layers. At least two periods of solution during calcite deposition were observed all over the district: (1) between the first and second calcite substages, and (2) between the second and third substages. A few other brief periods of solution corrosion may have occurred during the early part of calcite deposition.

A possible explanation of this solution of the limestones and dolomites is that when the ore fluids became corrosive enough to dissolve the wall rocks in large quantities, they could also precipitate sulfides and barite. The precipitation, in part, may have been the result of changes in composition of the solutions as large quantities of calcium and carbonate ions from the wall rocks were added to them. When the solutions had deposited most of their metal and sulfur fractions, they approached equilibrium, fluctuating slightly in composition. When supersaturated in calcium and carbonate ions, solution ceased and calcite was deposited (the source of which was the adjacent wall rocks). After some calcite was deposited and perhaps a slight quantity of sulfide-bearing waters added, sulfide deposition was briefly renewed and the calcite etched; this process was repeated at least twice. Afterward the solutions remained supersaturated in respect to calcium and carbonate ions until all the calcite was deposited, when they again regained equilibrium.

Pyrite stage.—The first sulfide deposited was pyrite, and it was generally a thin film on the walls of nearly all fractures in the ore deposits, as well as disseminated crystals that replaced the wall rock which borders the veins (fig. 52). Banfield (1933, p. 89–94) states that practically all of the iron sulfide disseminated in the rock beyond the veins is pyrite rather than marcasite. The pyrite film on the wall rocks is almost universally present in the ore bodies.

Preliminary studies suggest that the earliest pyrite, where crystallized, has octahedral faces whereas the later pyrite generally has cube faces. Where the early pyrite is unusually abundant, large reniform masses were developed inward toward the central parts of the veins (fig. 55). Pyrite formed over a relatively long period—with marcasite and, later, sphalerite and galena—but deposition appears to have ceased shortly after the main accumulation of sphalerite. The largest quantities of pyrite were deposited in the beginning and end of its stage of mineralization.

Marcasite stage.—The deposition of marcasite began immediately after the first film of pyrite was precitated. The earliest marcasite is on the inside surface of the pyrite bands against the wall rock within the veins, and generally a sharp contact separates the two minerals. Banfield (1933, p. 89–94) suggests that this sudden change took place after all the available apertures in the wall rock were filled by pyrite "armor-plating" the rock and protecting it from the rest of the solutions. This plating process by the pyrite followed by marcasite deposition suggests a change in the condition of the mineralizing solutions, possibly from alkaline to acid. Banfield suggests a possible explanation for "experiment has shown that pyrite tends to be deposited in alkaline and neutral solutions" (the expected condition where the unsilicified carbonate wall rock is exposed to the solutions), "but the deposition of marcasite is more likely in acid solutions to be expected after the pyrite plating." Reaction of mineralizing solutions with the wall rock, which apparently began at about the time that pyrite deposition commenced, is strongly suggested by the dissolving of the limy wall rock.

The accumulation of marcasite continued throughout almost the entire remaining period of ore deposition. It increased after the deposition of sphalerite had ceased, then gradually decreased, ending only after all other sulfide deposits had been emplaced and the two early calcite stages were completed.

Early platy barite stage.—Deposition of early platy barite appears to have taken place immediately after the deposition of the first pyrite and marcasite. In several specimens from the DeRocher mine near Shullsburg, barite was deposited directly upon the pyrite-marcasite film, and the surface that faces the vein center shows euhedral platy barite crystals upon which are perched crystals of the first sphalerite that was deposited. At the Thompson and other mines near Shullsburg, cavities that resulted from a redissolved, platy, crystallized mineral lie between the early pyrite wallband and the first sphalerite. The sphalerite was deposited on top of the now-dissolved platy crystals. The tabular platy habit of the crystal molds suggest that barite was the mineral removed.

Sphalerite (and wurtzite?) stage.—Sphalerite was the next mineral to deposit after the early, platy barite and is generally the most abundant mineral of the veins. Normally the sphalerite forms two bands on opposite sides of the vein, the crystals on each side terminating in the center (fig. 52). Some veins do not show this uniform symmetry, for in places they carry marcasite or calcite on one side (generally the upper) and sphalerite on the other. Fowler (oral communication to Behre, C. H., 1943) suggested that the marcasite or calcite has been later introduced on one side of a reopened fissure vein. The sphalerite tends to contain light and dark bands owing to changes in the composition of the solution during deposition. Greater iron or manganese content in some of the sphalerite appears to account for the darker bands. Much of the earlier sphalerite is darker colored than that part deposited near the end of the sphalerite stage. In places this darker colored sphalerite has been fractured, and the lighter colored sphalerite was deposited in the fractures.

Commonly the sphalerite is fine grained and botryoidal and contains prominent concentric banding in the veins (see lower sphalerite band between points 1 and 2, fig. 52). In such examples it strongly resembles wurtzite and may very well be that hexagonal form of zinc sulfide as previously described. However, the sphalerite of certain vein ore bodies and of disseminated deposits is coarsely crystallized without any resemblance to wurtzite.

Included within the sphalerite, and in places localized in specific layers, are small bands and nodules of botryoidal marcasite and crystallized pyrite where precipitation apparently increased in quantity towards the end of the period of sphalerite deposition.

Cobaltite(?) or safflorite(?) stage.—Where observed, the cobalt-arsenic mineral occurs in the marcasite deposited within sphalerite, and apparently the small deposits of this material were contemporaneous with the sphalerite.

Galena stage.—The first deposition of galena started fairly early in the sphalerite stage, and this mineral became progressively more abundant as the end of the sphalerite stage was reached. Dendritic intergrowths of galena in sphalerite are present. From an initial galena grain embedded in the sphalerite they spread conelike inward toward the vein centers.

The maximum quantity of galena was deposited at the end of the main period of sphalerite deposition and was accompanied by some pyrite, much marcasite, and a little sphalerite. The deposition of galena ceased before that of marcasite, the latter often being deposited as well-formed crystals upon an earlier core of galena.

The galena crystals occur as cubes, cubo-octahedrons, and more rarely octahedrons. Van Hise (1901, p. 104) considered this octahedral form to be later than the cubes, a relation corroborated by the present study. In places, a little reddish-brown sphalerite is deposited on the galena and marcasite of this stage.

Late barite stage.—Barite, accompanied by marcasite and in places by a little galena, was deposited next in order in the central parts of the veins. Wherever barite is present (except for early platy barite), it is later than the main period of sulfide deposition but most of it is earlier than the first calcite. The barite forms bands on opposing sides of the central parts of the veins and as botryoidal, globular masses filling the vein center. It is quite evident from the abundance of ore breccias cemented by barite, that renewed deformative movements took place just preceding or during the early part of this barite stage. The barite, in turn, is itself fractured and cemented by calcite, which indicates further movements at the end of the barite stage.

Chalcopyrite-millerite stage.—Chalcopyrite, generally in small quantities, and more rarely millerite, were deposited on the barite as crystals or crystal aggregates. The deposition of chalcopyrite began in minute quantities during the latter part of the sphalerite stages, as indicated by small bubblelike, exsolution blebs of chalcopyrite within the later sphalerite, the galena, and the barite. Where barite is not present in the veins, these two late sulfide minerals were deposited directly upon the earlier sulfides. A small quantity of marcasite is the only other sulfide deposited contemporaneously with the chalcopyrite and millerite. Their deposition continued into the period of earliest calcite deposition (fig. 58) but ceased after the development of the first type of calcite.

Calcite stage.—The final stage of mineralization is calcite deposition, which includes four substages. The calcite, wherever observed, was deposited later than any other mineral (fig. 58), except for very minor amounts of chalcopyrite, millerite, marcasite, and possibly barite which accompanied the earlier part of calcite deposition. The sulfides chalcopyrite and millerite ceased deposition at the end of the first substage of calcite deposition, but marcasite continued to form in very minute amounts during the first two substages of calcite deposition. The early calcite is quite cloudy and often colored; but as deposition continued and the remaining impurities were removed from the solutions, the calcite became progressively clearer until the final deposits are transparent and colorless.

The earlier cloudy calcite was in some places brecciated by minor renewed deformation, and the later clear calcite was deposited in the fractures, healing them.

A special consideration of calcite deposition is warranted because of certain peculiarities in the process. The calcite was deposited in a succession of four easily recognized substages (fig. 58). These substages are identified by a series of three scalenohedral habits and a final rhombohedral habit in the crystals. Between each substage an interval existed during which apparently some etching of the crystals occurred, and, in the first two intervals at least, a little marcasite was deposited. In some massive calcite these substages are less easily identified but can be distinguished locally by the color changes, increasing clarity of the calcite, and the presence of marcasite bands.

In some crystals these four habits that identify each substage can be seen as successive overgrowths, but generally only one or two overgrowths may be present (fig. 59). Chamberlin (1882, p. 491–497) first noted this change from scalenohedral to rhombohedral calcite, and Hobbs (1895, p. 115–121) described the four habits in their proper order. A brief description of the four habits follows:

Type 1. Habit—steep rhombohedrons modified by basal pinacoids or scalenohedrons modified by rhombohedrons, faces rounded and commonly deeply etched; color—milk-white, brown, orange-pink, or gray; cloudy from inclusions of marcasite, chalcopyrite, and millerite; surface commonly mottled with small marcasite crystals (fig. 60).

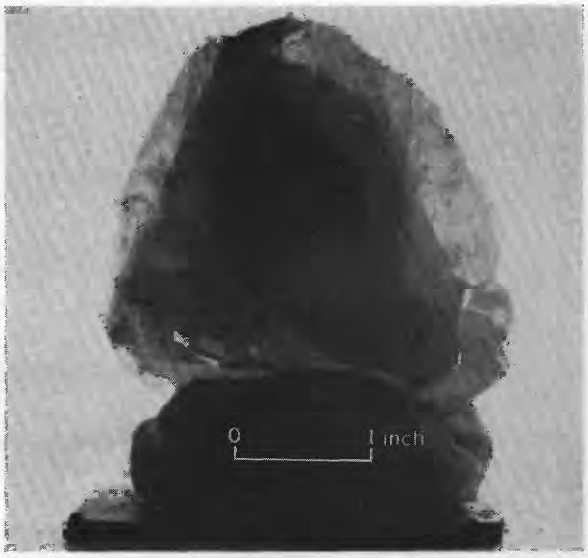


FIGURE 59.—Sectional view of a zoned calcite crystal which shows the first three substages of calcite deposition as increasingly clearer phantoms. Note the decreasing cloudiness (mostly finely divided sulfides) in the successive substages as shown by the increasingly light color and transparency. Bautsch mine, Galena, Ill.

Faust (written communication, 1955) studied a type 1 calcite crystal and stated that "the angles between crystal faces were measured with an arm protractor goniometer. The results of these measurements, while crude, together with the symmetrical arrangement of the faces serve to identify these faces as the basal pinacoid 0001, the first order rhombohedron 1011, and the second-order rhombohedron 0221. The results of the measurements are:

$$Cr=0001 \text{ and } 10\bar{1}1=44°36\tfrac{1}{2}'$$
$$Cf=0001 \text{ and } 02\bar{2}1=61°+$$

Type 2. Habit—sharp scalenohedrons alone; color—cloudy white but more translucent, or pale-yellow; surface—locally etched and mottled owing to the small marcasite crystals deposited upon it (figs. 59, 62).

Type 3. Habit—scalenohedrons moderately truncated by rhombohedrons, and much modified; colorless, fairly clear, though still slightly cloudy; generally with a core of type 2; no marcasite coating and etching uncommon (figs. 59, 61).

Type 4. Habit—rhombohedral highly modified; crystals clear, colorless, transparent, unetched; smooth or striated vitreous crystal faces, no marcasite inclusions or coatings (figs. 62, 63).

This sequence of calcite habits is prevalent through the district wherever calcite is found; the same order of deposition is always retained. Each type is typical of each equivalent paragenetic substage. The increas-

FIGURE 60.—Deeply colored type 1 calcite crystals, Liberty mine, Meekers Grove, Wis. These deep pink crystals, possibly colored by included manganese, are also identifiable by etched uneven faces as first substage calcite. They are a combination of steep rhombohedrons and an uneven (lighter colored) basal pinacoid. Photograph courtesy of E. N. Cameron, University of Wisconsin, Madison, Wis.

FIGURE 61.—Type 3 calcite crystal in which growth ceased in the later part of the third substage. A sharp scalenohedral phantom of substage 2 calcite is visible in the center of the crystals. The large rhombohedral faces indicate that this crystal ceased growth in the later part of substage 3. Note the smooth faces, marked transparency, and lack of sulfide inclusions, all typical of third substage calcite. Bautsch mine, Galena, Ill.

ing clarity and purity of the calcite strongly suggests that the succession of crystal habits is directly related to the changing composition and the increased purity of the depositing solutions in the final stages of mineralization. The etching of the crystals indicates a sudden change in the pH of the solutions; at present the reasons for this change are not clear.

POSTMINERALIZATION RELATIONS

At some time after mineralization had ceased, very minor deformation took place as indicated by a few postmineral, minor faults and fractures.

WALL-ROCK ALTERATION ASSOCIATED WITH THE ORE DEPOSITS

A notable feature of the upper Mississippi Valley zinc-lead district is the altered limestones and dolomites adjacent to the ore. Three main types of alteration were: (1) solution of the calcareous rocks; (2) silicification; and (3) dolomitization. Solution of the calcareous rocks was by far the most common and widespread; dolomitization and silicification was more local and less intense. "Sanded" dolomite and pyritized rock

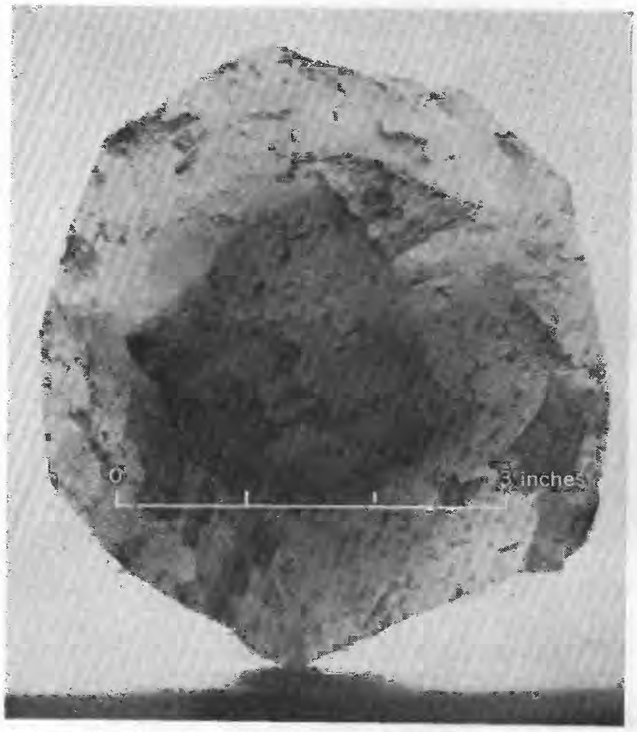


FIGURE 62.—Zoned type 4 calcite crystal that shows a marked scalenohedral type 2 crystal within it. From the Bautsch mine, Galena, Ill.

FIGURE 63.—Reverse view of the type 4 crystal shown in figure 84 illustrating typical flat rhombohedral habit and marked transparency. From the Bautsch mine, Galena, Ill.

are other types of wallrock alteration that occurred in many of the ore deposits, and at least one deposit of the Prairie du Chien group has been locally sericitized. Other deposits in this rock contain glauconite (?) or celadonite (?), that may have been deposited by the ore-bearing solutions.

(H, K)AlSiO4

The three main types of alteration are restricted to the rocks within the ore bodies themselves and their immediate border areas, plus other local areas through which the mineralizing solutions have passed but within which the quantities of minerals deposited are not sufficient to constitute an ore body.

Alteration of these types characterizes other areas in the Mississippi Valley region. It is developed to a much greater degree in the Tri-State district (Fowler, 1935, p. 106–163) and also in the northern Arkansas district (McKnight, 1935, p. 118–121, 129, 135).

SOLUTION OF THE CARBONATE ROCKS

Solution of the carbonate rocks is the most extensive type of alteration caused by the mineralizing solutions and was active in most of the ore bodies in the district. This process had its greatest effect on the limestones of the lower part of the Decorah and upper part of the Platteville formations. To a lesser extent the dolomitic beds of the upper part of the Decorah formation, and the Galena dolomite formations, and the Prairie du Chien group have been affected.

The chief effect of solution is to partly or completely remove the calcareous layers of the limestones, leaving only a residuum of the argillaceous material of the bed dissolved. In the altered areas this process, which will be referred to as "shalification," produces all degrees of end product from only slightly changed limestone to a lime-free shaly mass (fig. 64).

For example, the unaltered Guttenberg member of the Decorah formation consists of pinkish-buff sublithographic limestone with minor interbedded carbonaceous shale and has a total average thickness of about 12 to 14 feet. Where greatly altered, the Guttenberg member is a chocolate brown, carbonaceous residual shale mass about 6 to 10 feet thick (figs. 64, 37). This brown shale is the "oil rock" of Bain (1906, p. 39–41). He concluded that the shaly oil rock was a primary shale facies deposited in local depressions in the original sea floor. Bain did not recognize that the shaly oil rock of the ore bodies and the unaltered limy phase represent the same original rock. Similar alteration and leaching of the calcareous beds is a characteristic feature of the Spechts Ferry shale member and the upper calcareous half of the Platteville formation in mineralized areas.

The following stratigraphic sections show the amount of solution thinning in areas of strong alteration. Total thinning is 20 feet.

Member name	Local name	Average thickness within mining district (in feet): Normal phase		Leached phase
Guttenberg	Oil rock	13	6	7
Spechts Ferry	Clay bed	3	1	2
Quimbys Mill	Glass rock	9	3	6
McGregor	Trenton	30	10	20
		55	20	35

This 20 feet of solution-thinning is probably the maximum to be expected, as it represents the normal maximum thinning in each member. Commonly, however, in a given altered area, the beds are affected so unequally that one or two members may reach the maximum amount of thinning whereas the others are only slightly thinned. In most areas the observed solution-thinning of all these members totals about 10 or 15 feet. In a very few ore bodies, single members, such as the Guttenberg, are locally reduced to a minimum thickness of 2 feet.

Figure 65 represents an example of solution-thinning based on drill-hole data from a section across a large ore body. The two parts of the ore body lie along outward-dipping, steeply inclined reverse faults. The parts directly overlie and include two synclinal areas that show the greatest solution-thinning. The central barren area consists of a small anticline that is not only present in the underlying McGregor member but is even more sharply defined in the overlying beds of the Decorah. The Quimbys Mill and Guttenberg members are thinned the most in drill holes DD 17 and 55, directly within and beneath the thickest parts of the ore bodies and the main controlling fractures. The soft, plastic Spechts Ferry apparently has been squeezed away from the central anticline into the western syncline by the compressional forces. The Guttenberg and Quimbys Mill members are least thinned to the east and west of the ore body and at the crest of the central anticline. The expected maximum thinning of the rocks by solution in the center of the ore bodies, postulated by those who believe the inclined reverse faults are due to solution and collapse, is, instead, localized to two zones in the vicinity of the main inclined fracture systems, as would be expected if the solutions dissolved along previously existing fractures.

The shalified residuum formed by solution of the calcareous rocks is apparently closely related to preexisting fractures (fig. 39). It is most abundant in the rocks along the principal fractures and in associated shattered areas where the solutions gained easy access. In many shalified areas evidence of plastic flowage of the residues is abundant (fig. 38); lateral shortening by folds and faults is common; vugs are rare. In areas of thinning a great amount of lateral shortening is indicated by (1) measurements, (2) small isoclinal and recumbent folds, (3) tight minor faults, and (4) healed breccias in which the less-dissovled, more brittle fragments are embedded in masses of soft residuum (fig.

FIGURE 64.—Guttenberg limestone member and interbedded shale altered by the ore solutions to shaly residues. Note the progressive change from unaltered sedimentary rock (at right near knife) to thinned shaly residues at left. Graham-Ginte mine, Galena, Ill. Photograph courtesy of H. B. Willman, Illinois State Geological Survey.

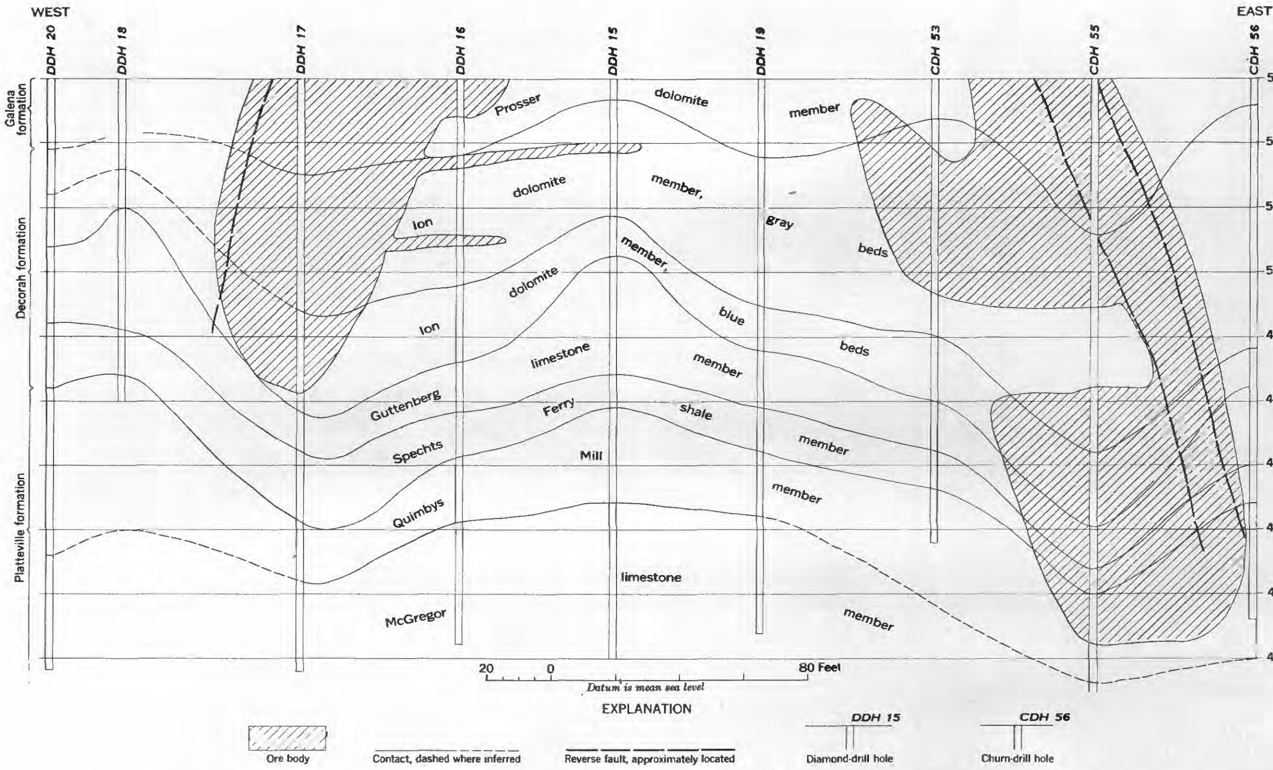


FIGURE 65.—Cross section approximately midway between shafts 1 and 2 of Bautsch mine, 5 miles south of Galena, Ill.

38). The uncrushed fragments are drawn out into lenticular eyes (augen) by the lateral flowage. The observations suggest that the shalification occurred during at least part of the period of regional folding by lateral compressive forces. The softening of the rocks by solution aided the deformation of the shaly residues by plastic flowage and they yielded much more readily to compression, both lateral-tectonic and by slump from above, than adjacent unaltered, stronger rocks.

The dolomitic strata of the upper Decorah formation and the Galena dolomite also have been altered by solution, but to a lesser extent. The more calcareous parts of the beds were dissolved and the magnesia-rich parts remained. Many of the dolomites were locally slightly thinned and shalified; and the more calcareous parts were dissolved so that irregular, small, solution cavities and tubes were formed in the more calcareous parts to form porous spongelike rock in areas along the feeding fractures. Presolution crackle-breccias along faults and other fractures aided this process by providing access for the dissolving solutions.

Shale produced by solution-thinning is restricted to the vicinity of ore bodies or, less commonly, to local channels in the rocks through which the mineralizing solutions passed. The presence of these shale residues, even where other evidence of mineralization is absent, suggests the nearness of mineralized areas. Studies of the degrees of alteration and thinning of the limestones and dolomites are very useful tools in locating and delimiting ore bodies because the intensity of shalification and the resultant thinning of the beds tend to increase nearer the main ore bodies.

Where silica or dolomite have been deposited by the ore-bearing solutions these earlier wall rock alterations have prevented later solution of the beds, except to a very minor extent. However, if all the limestone of an ore body has not been previously silicified or dolomitized, the remaining calcareous parts are usually dissolved in the same manner as where the earlier alterations are not present. These relationships indicate that solution and shalification were later than silicification and dolomitization.

The main fault, fracture, and fold patterns are very similar in ore bodies whether solution-thinning is present or absent. The slumping caused by solution-thinning commonly only distorts the folds and faults already formed by lateral compression. The beds overlying most of the thinned areas have sagged and slumped a little. The bedding planes in these sagging rocks have been opened in places, and small areas of slump fractures and solution breccias have formed. Tumbled breccias have been developed by solution collapse in a few ore bodies where the solution was greater than normal, such as in the Gensler ore body south of

Shullsburg, Wis., and parts of the Bautsch mine south of Galena, Ill. No evidence was found to suggest that local collapse due to solution-thinning formed the main fracture systems that localized ore deposition.

SILICIFICATION

Silicification of the rocks within and adjacent to the ore bodies is a prominent feature in the Prairie du Chien group and, to a lesser extent, in the overlying Platteville, Decorah, and Galena strata.

Silicification in the Prairie du Chien accompanies lead, copper, iron, and zinc deposits in the localities examined. The silica is in the form of massive and banded chertlike jasperoid that replaces dolomite beds in equal volumes, and as chalcedony and drusy quartz in banded, symmetrical veins and cavity coatings. The silica is most abundant along shears, in shattered zones, and as a replacement of selected beds or groups of beds that extend away from these zones. The beds, which are completely silicified near fractures, grade into unaltered dolomite away from these fractures. Veinlets and irregular replacement masses of jasperoid penetrate the original rock, and in places large replacement veins cut across the dolomite beds between two silicified layers. Premineral, bedded cherts are present in the mineralized zones, but many of them are obscured by the completeness of the later silicification. This intense silicification is apparently not present in unmineralized Prairie du Chien strata, inasmuch as only the original sedimentary chert nodules are observed in areas away from sulfide. The Prairie du Chien silicification closely resembles that of the Tri-State district as described by Fowler (1935, p. 106–163).

The slightly younger, pink dolomite, and sulfides occur in intimate association, filling vugs or fractures within the silicified areas.

The St. Peter sandstone is silicified along many faults and fracture zones. Silicified areas that lie directly beneath pitch and flat ore bodies have been found in this rock by drilling. The silica in these areas is deposited as crystal overgrowths on the rounded quartz sand grains and in places completely cements the sandstone into quartzite. Commonly pyrite and a little galena are deposited in the remaining pore space.

Silicification was much less intense in the Platteville, Decorah, and Galena, which contain the principal ore zone. In mineralized areas, the calcareous and shaly beds were replaced by chert, jasperoid, and an impure "cotton rock", both of which retain most of the texture and color of the original rock. Crystallized quartz is a rarity. Irregular masses of silica replace the rocks along main fractures, and selected beds for a short distance away from these fractures. In the Galena dolomite, the silica related to mineralization is deposited on the older sedimentary chert nodules as overgrowths of dark-gray chert with minute pyrite inclusions. These silica overgrowths occur only in intensely mineralized areas.

The process of silicification in the Platteville, Galena, and Decorah was generally confined to the areas of the larger zinc ore bodies. The silicified zones are less abundant in the northern part of the district than in the southern part, where local siliceous replacements of the calcareous Decorah and upper part of the Platteville are common in the ore bodies. Many of the wall rocks of the main reverse faults in ore bodies are replaced by jasperoid where the faults flatten along bedding planes. In such silicified areas beds of all stratigraphic units cut by the faults have been completely replaced by grayish or brownish jasperoid, or by a white, impure "cotton rock". Thin sections show a grain for grain replacement of the original calcite or dolomite by the silica. In many places the fossils were replaced by silica prior to the silicification of the surrounding rock, and where found alone are good evidence of incipient silification in rock that is otherwise unaltered.

Some silicified Guttenberg and Quimbys Mill strata retain so many of their original petrologic characteristics that the presence of the completely silicified rock can be determined only after careful physical and chemical tests. Where silicified, the rocks have been preserved from further alteration, and in these places they retain their original thicknesses and most of their petrologic characteristics.

An example of this type of silicification was observed in the Hoskins mine, New Diggings, Wis. Nearly all of the Guttenberg member of the Decorah formation is silicified, particularly along the main reverse faults and in the hanging wall of the mine. At first glance the rock appeared to be nearly unaltered limestone, but upon careful inspection the entire member was found to be silicified to a jasperoid that retains the appearance of the limestone it replaced. The silica replaces the entire rock mass, including the interbedded carbonaceous shales, with the retention of their brown color and textures. In other parts of the mine only chert nodules were formed.

Figure 66 graphically shows the results of the analyses of samples of the Guttenberg member in the Hoskins mine (pl. 12). The samples were taken at 50-foot intervals, commencing in the main Hoskins ore body and passing east through a barren drift into the East Hoskins ore body. The unaltered Guttenberg limestone member in the drift has an average CaO content of about 51 percent, and the argillaceous insoluble material averages about 5 percent. However, marked changes

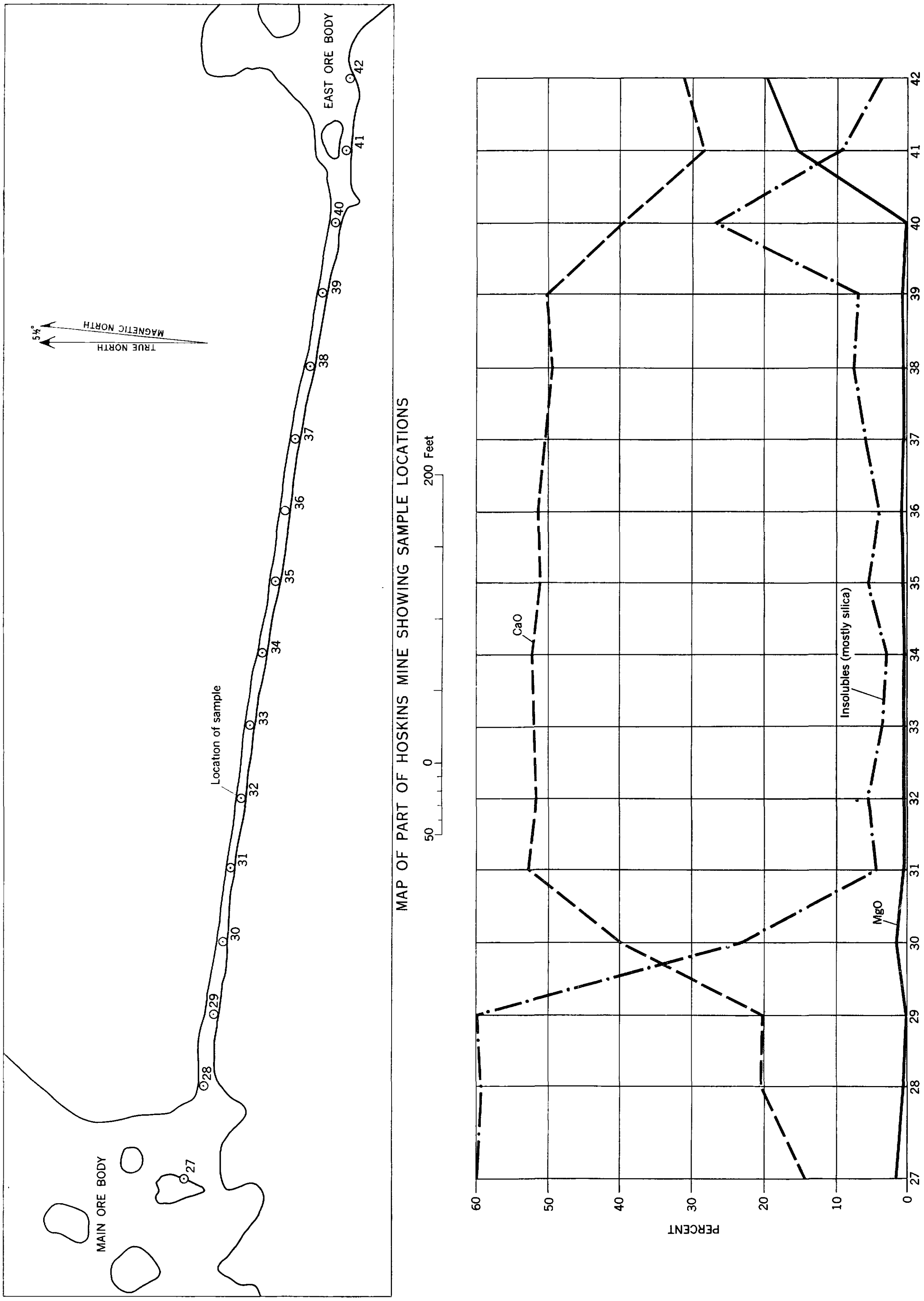


FIGURE 66.—Lime-magnesia-insolubles relations in Guttenberg member, shown in drift from one ore body through unmineralized ground to another ore body, Hoskins mine, S½ sec. 13, T. 1 N., R. 1 E., Wisconsin.

in the rock are observed as the ore bodies at both ends of the drift are approached. Toward the western (main) ore body, the CaO content drops from 52.5 percent at location D–31 to 20.5 percent at location B–29. Within this outer 100-foot marginal zone of the ore body is a series of minor, slightly mineralized fractures, and the main bedding-plane fault of the ore body. As the rock is very little thinned or shalified, the marked rise in the insoluble content from 4.5 percent at location D–31 to 60 percent at B–29 is probably mostly the result of replacement silica rather than argillaceous residues. In the main Hospins ore body, in the stopes to the west of location B–29, the CaO content continues to decrease slightly into the footwall area of the main reverse fault zone, and the silica and insoluble content remains nearly constant. The MgO content does not increase appreciably in the silicified rock of the western ore body. This low MgO content in the western ore body strongly suggests that the alteration dolomite, which is younger than the silica, could not replace to any appreciable extent the areas already silicified.

In the smaller, East Hoskins ore body, the mineralization was less intense and the CaO content does not decrease as much. Likewise, the increase in secondary silica is less, and is restricted to the outer fringe area of the ore deposit. However, in contrast with the main Hoskins ore body, the Guttenberg member has been dolomitized except where it has been silicified along the margins. The MgO content remains low through the silicified zone in the approach to the ore body from the west. However, it rises markedly from less than 0.5 percent at location M–40, to a maximum of 19.5 percent in the central part of the ore body, which indicates that the limestone has been nearly completely altered to dolomite. As in the main Hoskins ore body, very little solution-thinning and shalification occurred in the dolomitized strata, as apparently this later alteration was prevented by the earlier silicification and dolomitization of the limestone.

DOLOMITIZATION

Dolomite deposited during the early part of the period of mineralization is a common type of alteration in the district. The dolomite is pale-pink and is found in veins, in crystal crusts lining vugs, and as replacements of limestone. All of the limestone within and around some ore deposits, and locally, as at Mifflin, Wis., all the limestones in a restricted area, have been replaced by alteration dolomite. For example, in the Trego mine (fig. 67) at Platteville, Wis., the beds have all been completely dolomitized. Jasperoid is absent except for a little in the east end of the south limb of the ore body. The limestone of the Guttenberg in the western end of the mine has been completely replaced by pinkish-gray coarse-grained dolomite. The dolomitized Guttenberg member has been thinned only a little by solution; the unit has decreased in thickness to 10 feet from its original 12 feet. Stylolites along the smaller shaly bands are the other evidence of solution thinning in the dolomite. Vugs that contain pink, secondary dolomite crystals (in places coated by sulfides) are common in this mine; the vugs are not only in the dolomitized limestone beds but also in the overlying Decorah and Galena strata that were dolomite before mineralization. At several places vertical veins of fine-grained, pale-pink dolomite, locally 2 or 3 inches wide, cut across considerable thicknesses of the Ion member of the Decorah formation (fig. 67). These veins replace fracture walls within the ore body, and at places are accompanied by pyrite crystals. Many of the dolomite veins are brecciated or displaced laterally as much as a foot by bedding-plane slips; thus some lateral deformation occurred after dolomitization. The pink replacement dolomite is abundant along the upper part of the main reverse fault exposed in the mine, within the Galena dolomite. The premineral, brownish-gray dolomite along both walls of this fault has been replaced by pale-pink, porous, finely crystalline dolomite for a thickness of several feet, within which vugs lined with dolomite crystals are filled with still younger sulfides.

In highly silicified ore bodies, as the main Hoskins ore body (fig. 66) previously discussed, dolomitized rock

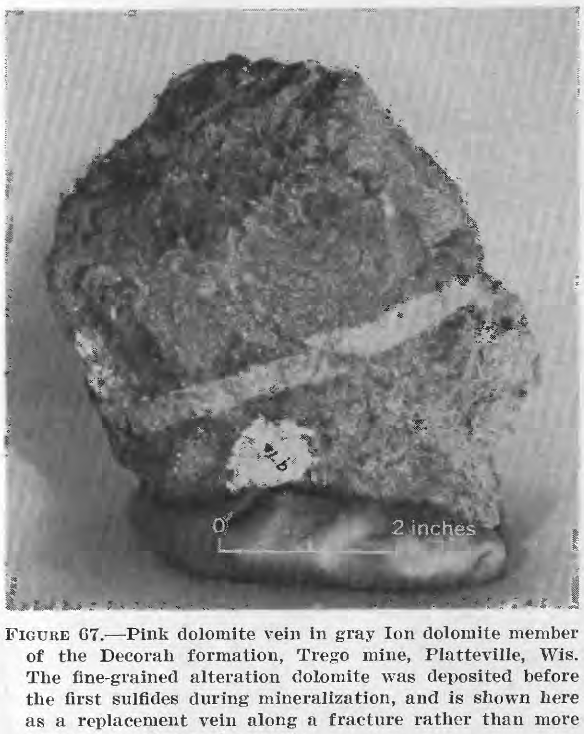


FIGURE 67.—Pink dolomite vein in gray Ion dolomite member of the Decorah formation, Trego mine, Platteville, Wis. The fine-grained alteration dolomite was deposited before the first sulfides during mineralization, and is shown here as a replacement vein along a fracture rather than more common massive replacements.

is only in very minor quantity because earlier silica replacement apparently prevented the later deposition of magnesium from the mineralizing solutions. Dolomitic alteration is absent in some ore bodies of the district.

Like the silica, dolomite replaces both the limestones and the calcareous material in the shales, and exhibits considerable preference for the limestones. Where dolomitization is complete, the rock is very similar in appearance to unaltered limestone except for slightly coarser grains and a sugary texture. Partly dolomitized rock is accompanied in many places by a little silica and some later shalification. Around the ore bodies, dolomitized rock grades into unaltered limestone and shale through a lateral distance of 50 to 100 feet away from the margins of ore.

Like the silicification, the dolomitization was more widespread and intense in the ore deposits in the Prairie du Chien group than in the overlying Platteville, Decorah, and Galena strata. And, like the silica in the Prairie du Chien, crystallized dolomite is far more abundant than in the upper ore-bearing strata.

LESS COMMON TYPES OF WALL-ROCK ALTERATION

Premineral and alteration dolomite rocks within and near many pitch-and-flat and gash-vein ore bodies have locally been "sanded" (Lovering and others, 1949, p. 27); that is they have been changed to a friable or incoherent mass of dolomite crystals. The cementing bond between the larger dolomite crystals was weakened by intergranular solution and many of the fine dolomite grains were dissolved by the ore-bearing solutions, probably during sulfide deposition. In ore-cemented breccias some dolomite fragments were selectively sanded in preference to others. In places only those fragments not replaced by silica or pyrite are sanded. Sanded dolomite is much more abundant in areas that are intensely mineralized. A similar-appearing dolomite sand is formed by weathering and ground-water solution along both barren and ore-bearing fractures above water table. Dolomite sand formed by weathering is distinguished by the unselective disintegration of dolomite near fractures and its increasing abundance towards the land surface.

The wall rocks of some ore bodies have been pyritized on all sides. Although both pyrite and marcasite are deposited in these areas, pyrite is more common and the term "pyritization" is used for this process to simplify terminology. Also in many places bodies containing many thousands of tons of wall rock have been pyritized near ore bodies, and in the St. Peter sandstone and formations of Cambrian age. Pyritized bodies are more common in the Platteville, Decorah, and Galena between Montfort and Arthur, Wis., and in a large area north of Benton than elsewhere. Many of the known areas of pyritization in the St. Peter lie directly beneath known pitch-and-flat zinc deposits, but others, partly or completely oxidized to hematite, are exposed in the eastern part of the district in structurally disturbed areas not closely associated with the known ore deposits.

At the Demby-Weist mine (fig. 1), 8 miles northeast of Dodgeville, Wis., silicified dolomite and sandstone exposed at the north end of the mine workings contain pearly flakes and crystals of sericite that are deposited along partings and in small cavities. This is the only ore deposit where this alteration mineral is known to be deposited.

Bright-green impregnations and films of a mineral, probably celadonite, are common in jasperoid of several of the deposits in the Prairie du Chien group. Celadonite is a possible alteration mineral that needs more study.

DETAILS OF THE STRUCTURES AND TEXTURES OF THE ORE BODIES

The following section describes in detail the controlling fractures, folds, and textures of the bodies. The possible ways that these features were developed by tectonic activity and solution-thinning are discussed by means of detailed descriptions of examples selected from 29 mines mapped geologically and many others examined. The types of ore deposits and their textures are classified in two principal groups: (1) those deposits in the main ore-bearing Galena, Platteville, and Decorah formations, and (2) the less numerous deposits in the rocks that are older and younger than these formations.

ORE-BODY RELATIONS IN THE ROCKS OF MIDDLE ORDOVICIAN AGE

The ore bodies, based on their structural relations, are classified into the following three types:

1. Fault-controlled pitch-and-flat ore bodies.
    a. Arcuate
    b. Linear
2. Gash-vein joint-controlled ore bodies.
3. Placer and residual deposits.

In both the pitch-and-flat, fault-controlled, ore bodies and the gash-vein, joint-controlled, ore bodies, symmetrically banded veins that fill fractures and partly replace their walls are the most abundant type of ore deposit; in both structural groups tectonic breccia deposits, solution breccia deposits and impregnation and replacement deposits are present.

FAULT-CONTROLLED PITCH-AND-FLAT ORE BODIES

These ore bodies exhibit many variations. Between the two distinct end member types—arcuate ore bodies and linear ore bodies—all combinations may be found. In general, arcuate ore bodies are more abundant along east- and northeast-trending folds, and linear ore bodies are more common in northwest-trending synclines. The few arcuate ore deposits in northwest-trending synclines have shorter axial lengths than most of those in eastward-trending structures. Although not common, elliptical ore bodies are present along both east- and northwest-trending folds (pl. 5). Most of the ore bodies, regardless of the direction the folds trend, occur on the flanks of synclines, but some are found on the flanks of anticlines. Where folds are asymmetric, ore bodies are commonly restricted to the steeper limbs.

The structures that control the pitch-and-flat ore bodies show a progressive increase in intensity of development from north to south. Only incipient structures localize the ore bodies of the northernmost part of the district, as near Dodgeville, Wis. An intermediate stage of structural development is seen farther south in the north-central part, between Livingston and Linden on the north and Platteville and Calamine on the south. The maximum stage of development of faults that control the ore bodies is exhibited in the southern part of the district. However, at places within each of these areas a few ore bodies exhibit development greater or lesser than is typical.

The following stages of structural development of the faults that control the ore bodies are typical of specific parts of the district:

First stage, northern part of the district.
: Bedding-plane faults the principal controlling fractures; reverse faults rare and only slightly developed; controlling folds 5 to 25 feet in amplitude; solution structures rare.

Second stage, central part of the district.
: Controlled by steplike system of almost equally developed bedding-plane and reverse faults; local controlling folds 20 to 40 feet in amplitude.

Third stage, southern part of the district.
: Commonly controlled by well-defined, smooth-wall reverse faults, which are more prominent than the bedding-plane faults; however, a considerable number of ore bodies exhibit the second stage of steplike fracture patterns; local controlling folds 30 to 70 feet in amplitude; solution structures common.

This increase from north to south in structural development exhibited by the fractures and folds controlling the ore bodies corresponds closely to a similar increase of the structures not directly related to the ore bodies.

ARCUATE ORE BODIES

Arcuate type ore bodies are the more common of the two types of fold-locallized mineral deposits. They are more common curving around ends of plunging synclines rather than around anticlines and are more abundant and better developed on the steeper limbs rather than the flatter limbs of asymmetric folds. All three stages of development of the structures controlling these arcuate ore bodies are numerous in the district. Detailed descriptions of mines in each stage are given below:

First stage

TECTONIC FEATURES

The Dodgeville No. 1 mine (pl. 10) is an excellent example of an ore body controlled by structures that were arrested in the initial or incipient stage of development. The eastward-trending ore bodies of the Dodgeville mine lie on the flanks of very broad open plunging synclines and anticlines that have a maximum amplitude of 15 feet. In the mine area the synclines plunge toward the west and the anticlines toward the east. The east-trending ore bodies are typical in pattern of many others in the district. The individual ore-bearing "runs"[28] of the ore body are 50 to 100 feet wide, and consist of a single connected vein deposit lying nearly horizontally at or near the base of the Quimbys Mill member of the Platteville formation. The ore bodies are fairly straight on the flank of the folds but curve at the ends to form crescentic or arcuate runs connecting the straight runs on the flanks. Linear ore bodies, which will be described later in this section, extend northwestward across the synclinal areas and connect the east-trending ore runs at fairly regular intervals like rungs on a ladder.

The ore bodies in this first stage of structural development have only one main fracture system, a widespread zone of bedding-plane faults. The main fault planes are most commonly in or near the soft, plastic carbonaceous shale layer that marks the base of the Quimbys Mill member. The main fault planes and subsidiary parallel faults above and below are marked by numerous slickensides, gouge, and breccia. Within the ore body the main fault planes contain fracture-filling, horizontal veins of zinc-lead ore that grade into replacement veins toward the edges of the ore body. At the lateral margins of the ore body, where the faults are commonly tight, the replacement veins grade into disseminated replacement and impregnation ore along the faults.

[28] "Run" is here used to indicate individual, straight, or regularly curved segments of the ore body.

The north part of the mine is in an arcuate ore body flanking an east-trending syncline, the central part of the mine is in an arcuate ore body flanking an anticline, and the southern part of the mine is in an ore body flanking a northeast-trending syncline. As the mine is in a connected group of ore runs, the interrelationships between the structural variations can be observed. In the discussion of this mine only the characteristics of the eastward- and northeastward-trending arcuate ore bodies will be covered.

Some small, mostly unmineralized, vertical fractures exist besides the bedding-plane faults; and, locally, inclined fractures are found, which in their greatest development in this deposit are reverse faults of small displacement. The east-trending ore runs are notably free of major fractures except for the bedding-plane faults. Also, solution effects are nearly absent except for a few inches on both sides of the main flat vein. These facts apparently preclude consideration of solution and collapse as the sole cause of the structure.

Because folds and bedding-plane faults are the only controlling factors observed, an extremely detailed study of these structures was made. A broad, low, east-trending synclinal area separates the south and north limbs of the north part of the east-trending arcuate ore body; this syncline is observable across the arcuate part at the west end and in all the northwest-trending ore runs crossing the syncline (pl. 10). The syncline is somewhat asymmetrical as its axis is much farther from the south limb of the ore body than from the north limb; also, an average rise of 13 feet was measured from the synclinal axis to the ore body along the south limb, whereas the rise was only 3 feet from the axis to the ore run following the north limb of the fold. Both ore runs plunge gently toward the west; the drop in the ore run on the south limb is 13 feet and 18 feet on the north limb, not including the curved part of the ore body around the west end of the syncline.

Near the center of the mine (pl. 10) is an eastward-pointing arcuate nose around the end of an anticline; extending west from the north end of this nose is the south limb of the part of the ore body that flanks an east-trending syncline. Therefore, the arcuate parts of the ore body extend without a break around a syncline, and an anticlinal nose, and then the ore run continues toward the southwest to a synclinal arcuate nose in the southwest part of the mine, similar to that first described.

The central anticlinal area is relatively simple structurally as compared to the synclinal areas to the north and south. It consists of a northeastward-trending anticline which has a steeper north limb, and plunges to the northeast. Crossing the anticline are several small synclines which are continuations of the northwesterly trending folds that also cross the large east-trending synclines ot the north and south.

The main fractures controlling the Dodgeville No. 1 ore deposit are bedding-plane faults that have been filled with veins of ore from 1 inch to a foot in thickness. Some angular fragments, which occur in the veins, are from the adjacent wall rock, which also has been replaced by ore locally. The rock bordering the veins is changed to a soft, sheared, clayey gouge by crushing, plastic flow, and a little solution. The largest of the bedding-plane faults is in or near a 4- to 6-inch mottled, brown, carbonaceous shale layer between the McGregor below and the hard, brittle, Quimbys Mill above. This soft plastic shale was apparently the zone of easiest bedding-plane movement in this part of the strata. In the mine this fault plane was observed everywhere, even though ore was lean or absent. This nearly horizontal fault continues beyond the mine walls toward the synclinal axes of the eastward-trending folds for an unknown distance.[29]

The bedding-plane faults in the Dodgeville No. 1 mine are marked by numerous slickensides, both along the zone of the main fault and also above, in minor, parallel, subsidiary slip planes along bedding-planes and thin shale partings in the Quimby Mill. In studying the nature of the faulting numerous observations of the slickensides were made to determine the direction and relative amount of movement of the beds. Strike readings of the slickensides were taken from their traces on the bedding-planes in the 170 places where they were exposed in the mine, and from this data analyses were made (figs. 68, 69). Tabulations of slickenside strike directions were made for eastward-trending and northwest-trending parts of the ore body and at intersections. Then a compilation was made of all the slickenside strike observations in the mine. The ore-body trends fall into two groups: eastward (F_1) and northwestward (F_2). It has already been noted that the eastward-trending ore runs lie on the flanks of broad, open folds, and that the ore runs parallel closely the fold trends. For these reasons the ore-trend zones are in practically the same directions as the trends of the folds. The correspondence can be observed on the geologic map (pl. 10).

The slickensides of the east and northeast ore-body trends are plotted on plate 10 and in diagram no. 1, figure 68. Most of the slickensides (the F_1 group)

[29] A drift, about 100 feet long and cutting unmineralized rock between the two limbs of the ore body flanking a shallow syncline in the Simpson mine (fig. 98, NE ¼ sec. 26, T. 6 N., R. 3 E.), shows a similar bedding-plane fault. This fault, observed in both limbs of the ore body, passes uninterruptedly through the 100 feet of intervening unmineralized ground. A similar situation is thought to exist at the Dodgeville mine, although here it could not be verified.

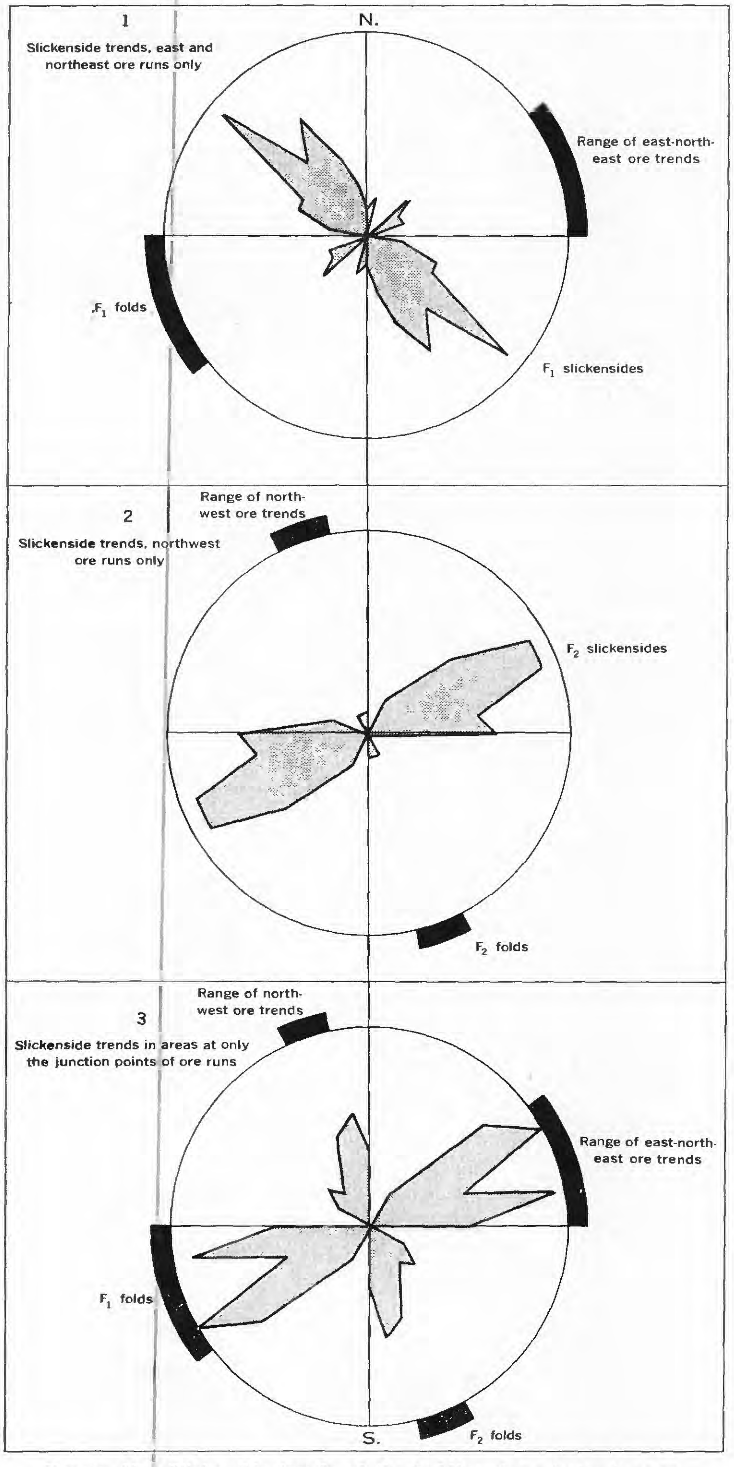


FIGURE 68.—Slickenside trends of the bedding-plane faults in relation to the folds and ore runs in the Dodgeville mine, Dodgeville, Wis. Plotted in 10° increment groups beginning at 10° east and west of true north. On the outside of the circle in each diagram, shaded areas show the ranges in which lie the controlling flexures and ore-body trends related to the slickensides. The easterly and northeasterly flextures and ore-body trends, as well as their related northwesterly striking slickensides are designated in the diagrams by F_1. The northwesterly flexures and orebody trends and their related easterly and northwesterly striking slickensides are designated by F_2. Each circle in the diagrams indicates one measured slickenside surface in the given direction.

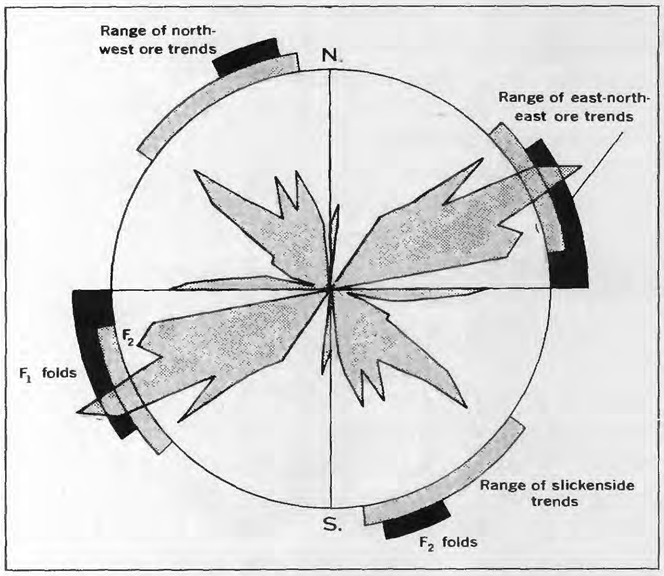


FIGURE 69.—Trends of all the slickensides measured on the bedding-plane faults in the Dodgeville mine ore body shown in relation to all the ore-body and fold trends. Plotted in 5° increment groups beginning at 5° east and west of true north. On the outside of the circular area of the diagram are two types of shaded areas. The narrow (shaded) area nearest the outermost circle indicates the strike ranges of the two principal slickenside groups, and the wider, outer (black) area indicates the trend ranges of the two flexure and ore-body groups. The easterly and northeasterly flexures and ore-body trends, as well as their related northwesterly striking slickensides are designated as F_1. The northwesterly flexures and ore-body trends and their related easterly and northeasterly striking slickensides are designated as F_2.

mapped in eastward-trending parts of the mine are directed northwest at nearly right angles to the ore body and fold trends. Thus the tectonic force that caused the bedding-plane slickensides in these parts of the mine moved the beds northwesterly or southeasterly; the average slickensides strike about N. 50° W. If such a force acted in this direction, compression of the beds would result in a series of folds transverse to this trend; and probably, as the compression continued, parting and movement along the most favorable bedding-plane layers [30] would take place. This parting of the basal Quimbys Mill strata along the bedding-plane faults tends to occur along the limbs of the folds, where the compression forced the beds in the anticlinal areas upward and toward the syncline. A minor slickenside group (F_2) that strikes northeast is shown in diagram no. 1, figure 68, in addition to the major slickenside group (F_1) directed to the northwest. By referring to diagram no. 2, it can be seen that this minor group becomes the major group in the northwestward-trending ore runs.

[30] The most favorable layer for movement in the strata of the Dodgeville area is the soft, carbonaceous, plastic shale bed at the base of the Quimbys Mill member as the Spechts Ferry shale, the more usual plane of movement, is very thin, hard, and gritty here.

Diagram No. 2 shows the strikes of the slickensides in the northwest-trending ore runs; they strike toward the northeast, at right angles to the northwest ore-body trends and folds. The northwest group (F_1) of slickensides in these ore runs is rare.

At the intersections of the northwest and northeast ore runs the slickensides groups, F_1 and F_2, are present in nearly equal quantities (diagram 3, fig. 68; and pl. 10). The forces apparently acted in one direction at one time and later in the other; probably the result was repeated movement in each direction at different times.

Figure 69 shows the total picture of the slickensides, folds, and ore trends of the entire mine. Compare with diagram 3, figure 68, and the similarity at the intersections of ore bodies is immediately apparent.

Other evidences of the interaction of two tectonic forces are observable in the mine. Although F_1 slickensides are far more abundant than F_2 slickensides in the northeast of F_1 ore runs (pl. 10), some F_2 slickensides are present. In the northwestward or F_2 ore runs, F_1 slickensides may be found. Also, in a few places in the mine, slickensides curving from the F_1 to F_2 direction and vice versa can be observed. At one place in the mine unusual zigzag slickensides were found. The grooves curved sharply from northwest to northeast without a break, showing continuous movements alternating in the two directions (fig. 70).

In other parts of the mine one slickenside direction is obscured by later slickensides of a different strike; so the age relations of the different directions can be determined. A table showing these determinations follows.

Directions of crossing slickensides	*Number of places observed*	*Age relationship*
North-northwest-northeast.	1	The northeast slickenside direction was the last. The age relation between the north and northwest-striking slickensides could not be determined.
North-northwest	2	The northwest direction of movement was last.
East-northeast	1	The northeast direction of movement was last.
Northwest-northeast	3	The northeast direction of movement was last.

Although the directions of movement are listed only in terms of the northern quadrants in the table and in the discussion which follows, it is to be understood that the beds in these examples may have moved in either the direction given or in the opposite direction, as the forces acting in one direction were balanced by others acting in the opposite direction; also in any given structure the actual directions of movements of different parts could not be always definitely ascertained.

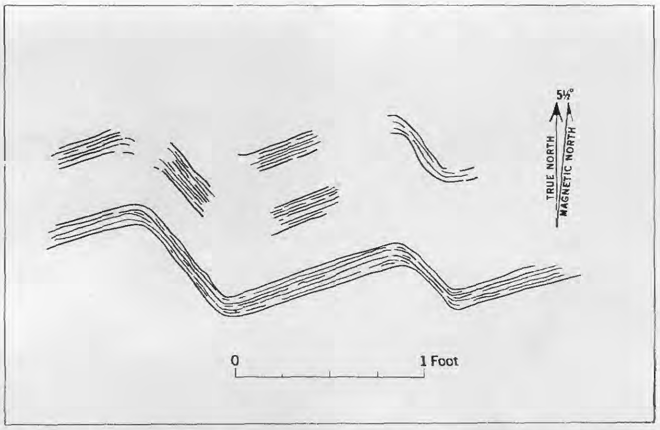


FIGURE 70.—Sketch of zizag slickensides on a bedding-plane fault surface in the Dodgeville No. 1 mine. Slickensides shown as viewed from above on the horizontal fault plane. Nearby structural relations indicate the beds above the fault plane probably moved with a zigzag motion from the east towards the west in relation to those below. For their location in the mine see point A, plate 10.

From the table of slickenside relationships a sequence of movements can be compiled. Commencing with the earliest they are:

1. A movement of the beds in the north direction, which indicates the direction of the forces that formed the bedding-plane faults on the flanks of the eastward-trending folds. The northward-trending slickensides are found everywhere except in the northeastward-trending ore run along the south limb of the eastward-trending anticline in the central part of the mine. An east direction of movement started either at the same time as the north direction or shortly thereafter.

2. A northwestward direction of movement indicates a slight reorientation toward the west of the earlier north-directed forces. The northwestward movement was followed or accompanied by a northeastward movement that probably represents a similar slight change in direction of the earlier east movement. The zigzag slickensides indicate that the northwestward and northeastward forces acted alternately at times during this period of movement.

3. Northeastward-directed forces, which continued to act after the other movements had ceased is suggested by the fact that northeastward-alined slickensides commonly obscure parts of the others.

From this sequence, explanations for some of the peculiar structural features in the ore body are possible. For example, the unusual zigzag slickensides (fig. 70) suggest that at part of the time the northwestward and southwestward forces were interacting as a series of successive alternating forces pulses. When one movement had relieved some of the stress caused by one force, the other force became dominant and movement for a time occurred in that direction; this alternation of forces was repeated several times. The end result of the successive applications of the two force directions was a movement of the beds along a direction slightly north of west. The zigzag slickensides are not present at an intersection of the two ore runs (point *A*, pl. 10) but occur in a typical east-trending ore run between intersections. This location and other evidences given below indicate that, though the forces conflicted more often at the intersections of the ore runs, they also conflicted far from these intersections. To cite two of many examples, curved bedding-plane slickensides are located in the southwest part of the mine (point *B*, pl. 10) along the northeast-trending ore run 200 feet from the nearest intersecting northwest-trending ore body. These curved slickensides, which change their strike from N. 82° E. at the southeast end to N. 52° W. at the northwest end, are possibly the result of local force couples or of rotational movements owing to the increasing dominance of one of the opposing forces. Conflicting movements this far from junctions of ore runs would appear to necessitate the presence of widespread bedding-plane faults, probably extending considerably beyond the mined limits of the ore runs.

These curved, or in places radial slickensides are most abundant at the intersection of the two ore trends where they show the interaction between the two active force directions and the tendency for one to become increasingly dominant over the other in relation to time and local resistances of the rock; thus the beds were subjected to rotational movements along the bedding-plane faults as the result of local force couples. A good example of rotational movement as shown by curved slickensides can be seen at point *C*, plate 10, in the west central part of the mine where well-developed striae curve from due east to N. 43° E. An example of radial arrangement of slickensides can be seen at point *D*. plate 10, where the slickenside strikes change progressively from N. 85° W., to 60° W. on a 50-foot in diameter bedding-plane. This radial pattern is apparently due to increasing dominance of the northeasterly directed forces over those directed northwesterly, plus some elasticity of the beds themselves. Other evidence of the action of rotational and interacting forces is found in curved fractures throughout the mine.

All bedding-plane slickensides along north and south limbs of the eastward-trending anticline strike nearly at right angles to the part of the ore body in which they lie, except near the intersections with northwestward ore runs, where some have eastward strikes. At the eastern nose of the anticline (point *E*, pl. 10) only a few slickensides were observed, but they seem to indicate that the directions of movement radiated around the nose at right angles to the ore run.

The main bedding-plane fault and subsidiary faults above and below are marked by numerous slickensides that show the average movement to be N. 34° W. Probably the first movement was approximately north, later movements in a northwesterly direction, and probably the last movement, particularly near the intersections with the northwestward ore runs, was in a N. 65° E. direction. Rotational movement of the beds near the junctions of easterly and northwesterly ore runs, and indications of zigzag movements, illustrate the interaction of the two force directions.

Several types of faults and fractures were observed in the Dodgeville mine. The bedding-plane faults, previously described, are the most important type; the others follow:

1. Low-angle reverse faults or fault zones.
2. Vertical or steeply inclined joints or similar narrow fractures.
3. Normal faults.
4. Numerous minor, commonly very narrow, inclined, vertical or irregularly dipping fractures, generally of short linear extent.
5. Breccias and fracture networks.

Low-angle thrust or reverse faults occur at several places and, except for the bedding-plane faults, they are the most prominent fractures observed. Good examples were seen along the northwest-trending ore run just east of the shaft (pl. 10) and at many other places in the mine, particularly in the central south part. Most of these reverse faults are associated with northwest-trending structures, but several are definitely associated with those structures trending easterly and northeasterly. Each of these faults is a direct outgrowth or branch of the main bedding-plane faults, and in every example the reverse faults dip toward an anticline, in most places toward the more important anticlines but in one or two places toward minor, local ones. These inclined fractures always commence nearly imperceptibly as a nearly flat branch of the main bedding-plane fault and usually start to rise where the bedding-plane fault begins to dip markedly toward the syncline on the anticlinal flanks. As the bedding-plane fault drops down the branch plane rises at a low angle from it and gradually increases in dip. As it rises it steepens until at the roof of the stopes the fault plane may have a dip of between 20 and 50 degrees. Immediately beneath the steepening part of the inclined fracture, but commencing in the footwall side where the two planes separate, a marked drop of several feet can be seen in the beds. Along the inclined fault plane the beds are flexed into a very marked reverse fault drag. In some of these faults the reverse displacements are as much as 6 to 10 inches, not including drag. The faults are mineralized with marcasite and calcite, which are late minerals in the ore deposition sequence; thus these faults may have formed during the later stages of deformation. The flexing of the main bedding-plane fault just beneath the inclined fault planes also indicates that the inclined fractures were formed when movement was more difficult along the ore-filled bedding-plane fault than in the vertical plane.

Most of these east-trending reverse faults and fault zones may be directly related to the more important folds and their accompanying ore runs. Some of these fault zones (see especially the southeast end of section *A–A′* on pl. 10) lie directly in the ore runs and dip toward the anticlinal area in each place observed. Others, such as the strong ones at points *F* and *G*, plate 10, are a considerable distance away from the ore runs but are parallel to them and dip also into the anticlinal areas. The location of the reverse fault zones is probably dependent upon local, steeply dipping areas on the fold limbs where the lateral thrust movement tended to break across the beds rather than parallel to them. These fractures have all the structural characteristics of incipient pitches and are commonly filled with marcosite.

The low-angle reverse fault near the shaft is a notable exception to the rule that inclined faults dip toward the major anticlines bordering east-trending structures. West of the shaft this fault (pl. 10) strikes due west, but east of the shaft swings southeast in an arc. The fault, which dips southward at about 10 to 15 degrees and is accompanied by reverse-fault drag and by a synclinal area toward the north, merges at its base with the rising bedding-plane fault. The rocks in the area toward the south of the fault rise to form a local east-trending anticline. This minor structure probably crosses the northwest-trending synclinal ore body just to the east and the next one farther east. A similar parallel less developed anticline is just north of the next east-trending part of the ore body to the south.

Strong, vertical, or steeply inclined fractures are notably rare in the east- and northeast-trending ore bodies although they are abundant in northwest-trending ore bodies. A few of these fractures extending parallel to the ore bodies are shown on plate 10; probably they are tension cracks caused by bending and fracturing during the bedding-plane fault movements.

Normal faults are few, but some of the inclined small fractures that border and dip opposite to the reverse faults are incipient normal faults.

In many places in the mine, particularly in the brittle beds of the Quimbys Mill immediately above the main bedding-plane fault, the rock has been brecciated by crushing during faulting.

The part of the ore deposit of the Dodgeville mine that swings around an anticlinal axis well illustrates the direct relationship between the anticlinal type and the synclinal type, as the ore-body characteristics are similar throughout.

The anticlinal area consists of a fairly simple gentle arch with its steeper limb on the north. This type of asymmetry indicates that the arch developed by an active forces in the northerly direction. On the flanks of the anticline, and swinging around the eastern-plunging nose, a bedding-plane fault extends down the flanks of the fold toward the synclinal axes. Movement along this fault was generally at right angles to the trend of the ore deposit; and, possibly, the beds above the bedding-plane fault in relation to the beds below this fault, moved away from the anticlinal axis. Where the fault movements reached a point beyond which shearing was easier in the vertical than in the horizontal plane, incipient reverse faults and fractures were formed; these dip toward the anticlinal axis. Deformation ceased before further development of the fractures.

The arcuate noses of the folds were developed by joint action of eastward- and northward-directed forces This action kept the rocks under general compression from all sides; thus shearing took place around the axial noses of the folds.

Bedding-plane faults probably do not extend across the anticlinal axial area. This absence is suggested by the lack of transverse, northwest-trending, ore bodies despite the fact that slight folds and vertical fractures appear to continue across this area.

Incipient reverse faults are in several places in the mine, and in each place they are an upward branch of the bedding-plane faults on the flanks of folds. These reverse faults always dip toward the anticlinal areas and are accompanied by drag synclines and drag flexing of the beds. They appear to be the initial development of the pitches so prominent in the more highly developed ore-controlling structures elsewhere.

Other vertical and inclined fractures are few, and seem to be either minor tension or shear fractures related to the bedding-plane faults, or, in places, are incipient fractures which would have developed later into reverse faults.

SOLUTION FEATURES

Solution thinning of the beds, at a minimum in the Dodgeville mine is found only in a narrow zone bordering the bedding-plane faults. The visible solution thinning is not sufficient to have any noticeable effect on the structure, except perhaps a widening by slump of 2 or 3 inches of the bedding fault fracture in which the ore was deposited. The beds of the Quimbys Mill are dolomitized in a somewhat local zone within and bordering the ore deposit. This dolomitization may have been produced by ore solutions as elsewhere in the district, but also might have been in part the result of a regional, pre-ore, dolomitization of the Quimbys Mill, as Dodgeville is probably near the western fringe of the area in which this member is regionally dolomitized.

HYPOTHESIS OF ORIGIN

The relations of the structures of the ore body indicate that they were apparently all developed by interacting tectonic forces. The principal forces appear to have acted from the north-south direction, as is shown by the asymmetry of the eastward-trending anticlines with their steeper north limbs and by the largest synclines, which have east axial trends. Movements commenced on the limbs of the folds along the soft, plastic, shale layer at the base of the Quimbys Mill member as the folding continued. This formed a bedding-plane fault, probably restricted to the limbs of the folds. Possibly the initial part of this movement caused the beds above the fault plane to move toward the anticlinal axes; but as the compression increased and the elastic limit was reached, the direction of movement was reversed and the overlying beds were thrust toward the synclinal axes. During these first deformative movements a less active, probable holding forces were developed in the east-west direction, preventing the eastward elongation of the folds and developing their arcuate form.

As compression continued the forces changed their direction, one group of forces acting in a N. 34° W. direction and the other in a N. 65° E. direction. This interaction between the two groups of forces tended to complicate the movement along the bedding-plane faults, the movements being in the direction of the component that gained local dominance. Other folds and bedding-plane fault zones were formed transverse to the first; these trend about N. 20°–30° W. Possibly they were localized here by the previous existence of a series of northwestward-trending shear joints that formed lines of weakness at regularly spaced intervals. The N. 65° E. directed forces possibly tended to extend the bedding-plane faults toward the axial areas of the east-trending synclines. Toward the end of the period of compression both of these forces attained such a magnitude of stress that relief was easier in the vertical than in the horizontal plane; and reverse faults began to form in the areas of unusually steep dips on the limbs of the folds, branching upward from the initial bedding-plane fracture. Deformation ceased before further development of the structure, dying out in a final movement by the forces acting parallel to the N. 65° E. direction.

This hypothesis is compatible with the regional deformation picture. The theory of origin of the structures of the district compares closely with the structural evidence observed in the Dodgeville mine. Also, the theoretical directions of the forces throughout the district compare closely with the sequence of movements in the mine, as determined from the structural study. A direct comparison can be made between plate 5, which illustrates the two general zones of fold trends in the Hazel Green-shullsburg area, and figure 69, which illustrates the slickenside, fold, and ore-run trends observed in the Dodgeville mine. The folds, ore-trends, and slickensides fall within the two general zones of folding in the district.

Second stage

The main features of the second stage of structural development are as follows:

1. The controlling folds have greater amplitudes and steeper limbs, are less broad and less open; minor flexures are commonly sharp and well defined, exhibiting a regular pattern.

2. Bedding-plane faults, reverse faults, and subsidiary fractures are well developed through several stratigraphic horizons; the combination of the two main fractures forms a step-like pattern composed of alternating bedding-plane faults and reverse faults (fig. 71).

3. In restricted areas, largely owing to local weakness or strength of the deformation, small parts of the ore body exhibit fracture systems typical of the incipient first stage and the better-developed third stage.

4. Solution was more prominent alteration during this stage, (fig. 64). (However, in the Trego mine solution thinning appears to have played but a small part.)

TECTONIC FEATURES

The Trego mine (pl. 11), at the north edge of Platteville, Wis. is in an arcuate ore body that illustrates bedding-plane and reverse faults of the second stage of development. The largest part ore body lies along the flanks of an eastward-trending syncline that plunges slightly to the east and has an amplitude of 25 feet. Along each flank of the syncline are narrow linear ore runs 40 to 100 feet wide, which trend parallel to the axis of the syncline. At the west end of the fold a marked arcuate nose is developed. This ore body exhibits a pattern and structural relation very similar to the east-trending ore body in the north half of the Dodgeville mine (pl. 10). The main difference between

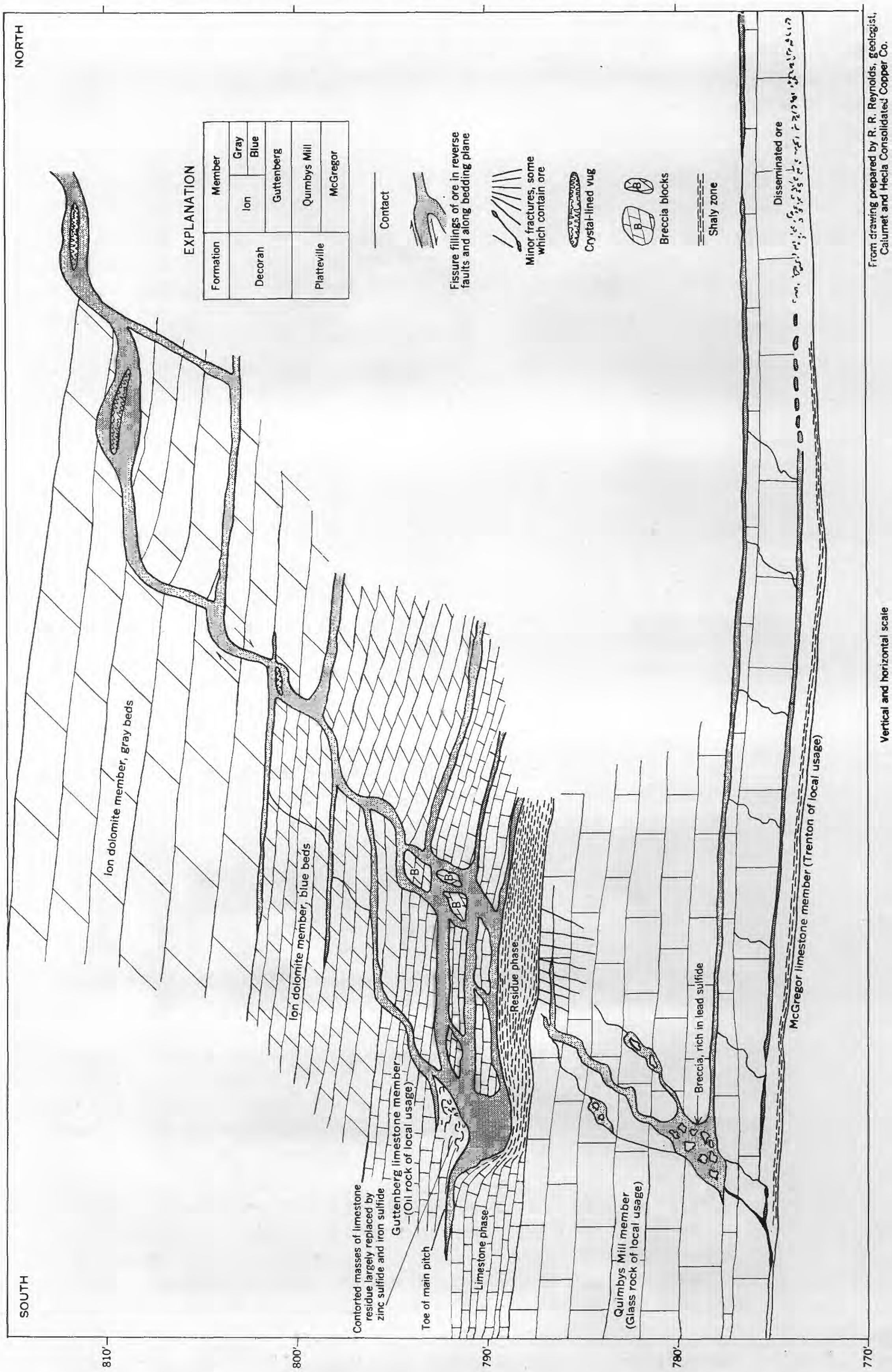


FIGURE 71.—Detailed drawing of a typical second stage ore-bearing fracture zone, South Hayden ore body, Calumet and Hecla mine, Shullsburg, Wis. The drawing shows well the typical steplike pattern development, as well as the marked solution thinning and shalification of the lower part of the Guttenberg member which permitted a slight slump in the beds, that was sufficient to open the overlying fractures to permit the deposition of the ore veins. Breccia blocks (B) consist of blue beds of Ion age.

the structural pattern of the Trego ore body and the Dodgeville ore body is the absence of the intersecting northwestward-trending structures and associated ore bodies which are in the Dodgeville mine.

The Trego ore body lies entirely above the Decorah-Platteville boundary. The "clay bed" or Spechts Ferry shale member is observed at only one place in the mine. The ore body is controlled by well-developed reverse and bedding-plane faults, which commonly have a step-like pattern. Locally, on the south limb, as in the area between the west arcuate nose of the ore body and the Trego shaft, the reverse faults show the third stage of development, namely well-defined, smooth-walled, inclined fractures with less prominent flats or bedding-plane faults. Thus this mine shows also the development from the second to the third stage and the differences between them.

In the part of the syncline enclosed by the arcuate ore body several subsidiary folds occur. A minor drag syncline lies immediately beneath, or a short distance into, the foot wall area of the reverse fault zone throughout the mine, and it forms an arcuate trough lying along the inner side of the ore body for its entire length. This syncline is broad and shallow and lies far in the footwall, where the main fault zone is weak, but the syncline is narrower and deeper and lies next to the fault zone where it is strong and well developed. Between these two drag synclines, near the west arcuate nose, is a marked, low anticline following along the axis of the larger general synclinal basin. This anticline splits farther east into two branches, one of which follows the inside fringe of the north limb and the other the inside or north fringe of the south limb of the ore body. A similar pattern relationship of minor folds is observed in the south synclinal part of the Dodgeville mine (pl. 10).

At the east end of the north limb of the Trego mine (pl. 11) mining has proceeded about two-thirds of the way around an anticlinal nose. The anticlinal part of the ore body is directly connected with the part of the ore body that flanks the synclinal nose to the west, showing the direct relationship between the two structural types.

As in the Dodgeville mine, this anticlinal area is structurally relatively simple compared with the synclinal area. It consists of a low, north-trending, anticlinal prong that plunges toward the south; the only subsidiary fold is the minor drag syncline that follows in the footwall of the aruate fracture zone curving around the end of the nose. As in the synclinal nose at the west end of the mine, the drag syncline becomes broader and more open as it passes around the axial nose area of the main fold.

The general faulting relations in the Trego mine can be seen by an examination of the geologic map (pl. 11) and the accompanying cross sections.

The controlling faults are of two principal types:

1. Bedding-plane faults.
2. Reverse faults.

Subsidiary to these and to the folding are two other types:

1. Vertical tension fractures near and parallel to the axis of the central syncline.
2. Normal faults near the bedding-plane and reverse faults.

Bedding-plane faults are a characteristic feature in the Trego mine, occurring at several favorable stratigraphic horizons. The initial bedding-plane fault is exposed only in a sump about 200 feet northwest of the shaft, at the south wall of the mine. This fault is in the soft plastic shale of the Spechts Ferry which in the Platteville area is a more favorable locus for the initial bedding-plane fault than the Quimbys Mill member.

In the sump the "clay bed", which is sheared and had flowed plastically, contains a vein of zinc and iron sulfide. A reverse fault branches from this mineralized fault and curves upward and steepens in dip as it rises. The reverse fault has a 2-foot displacement and forms a pitch containing a vein of iron sulfide.

Ore- and gouge-filled flats mark the location of other bedding-plane faults at one or more prominent planes above the initial bedding-plane fault in the Spechts Ferry shale number. These bedding-plane faults show horizontal slickensides, particularly in the brown shales of the Guttenberg limestone member beds; but in the coarse-grained dolomitic beds above, they are less common and obscure.

The bedding-plane faults are connected by a series of parallel, inclined, ore-filled, reverse faults (pl. 11) or pitches. These faults have a displacement of 6 inches to 2 feet. The inclined faults rise from the initial bedding-plane fault at an angle of about 45 degrees. While the faults were developing, the movement of the beds in the hanging wall relative to the beds in the footwall apparently acted upward along the inclined fracture until a prominent bedding-plane was reached; then the force was transmitted horizontally for a time, the top bed moving over the lower one along the bedding plane until another zone of weakness or the elastic limit was reached and again an inclined fracture formed, and movement along it continued upward to the next successive prominent bedding plane. Thus a step-like fault pattern was formed. As the compressive force continued, other similar fractures were formed in the footwall area of the first reverse fault, and gradually a network of inclined and horizontal faults developed.

Most of the beds cut by the reverse faults were apparently dragged by the movement along the faults and formed synclines in the footwall area. The drag by the reverse fault movement tended to lift the hanging-wall beds of the bedding-plane faults particularly at their junctions with the reverse faults. Thus wedge-shaped openings that are widest at the reverse faults resulted. This wedge-shaped opening provided free access to the ore solutions along the bedding planes. The inclined faults are commonly tighter fractures than the bedding-plane faults.

As the movements along the reverse faults continued to develop, the force component that lifted the hanging wall along the inclined planes tended eventually to break across the beds above the angular junctions with the bedding-plane fractures and formed a series of continuous inclined fractures—the rhombic fault system or network typical of the third and final stage of fault zone development (pl. 11, section *C–C′*, south limb of mine).

The reverse faults on the two limbs of the ore body dip toward the anticlines north and south of the main controlling syncline. This relationship is similar to that observed in the incipient reverse faults of the Dodgeville mine. The fault zones apparently were formed by lateral compressive forces that acted in north and south directions, and a lesser force acting east and west, which helped form the arcuate noses. These forces apparently tended to move the beds above the Spechts Ferry along this incompetent member as a slip plane. Movements probably began along bedding-planes; but later, after the elastic limit was reached and movement in the vertical plane was easier than in the horizontal plane, reverse fault zones developed on the fold flanks. This faulting continued around the arcuate noses at the west and northeast ends of the folds because the area was probably under general compression simultaneously by the north-south- and east-west-directed forces.

The reverse faults terminate upward by flattening in dip and joining bedding-plane faults, or they continue as inclined shears that weaken and die out upward.

The fault zone and accompanying drag folds along the north limb of the ore body are directly connected to and similar to those at the anticlinal nose in the northeast part of the mine (pl. 11). At the anticlinal nose the fault zones reach the third stage of development. As they swing around the nose the reverse faults diverge, and the footwall drag syncline widens. A similar structural picture may be observed at the west synclinal nose.

A few small normal faults, subsidiary to the main fractures of the fault zones, occur as irregular, open fractures that dip opposite to the reverse faults and lie within the reverse fault zones or in their footwall area. The normal faults appear to be due to tensional opening of the beds, transverse to the shearing. Small, tight, smooth-walled normal faults have been formed by a slight rotation and subsidiary shearing of the beds beneath one of the prominent bedding-plane faults (pl. 11, section *D–D′*, south limb).

Open vertical fractures parallel the main synclinal axis and cross the ore body at its west arcuate nose, vanishing into the hanging wall of the west mine stope. They may have been formed by tension along the axis of the fold with some renewed adjustments as the later subsidiary folds and faults were formed.

The ore of the Coker mines (pl. 2) at Mifflin, Wis. are also controlled by step-like systems of reverse and bedding-plane faults of the second stage of development. Coker No. 2 mine is in a large elliptical ore body completely enclosing an anticlinal structure. The step-like fault zones dip on all sides toward the central anticline. Near the west end a southeastward-plunging syncline lies between the main south limb of the ore body and the southeastward prong. This prong is controlled by a southwestward-dipping reverse fault zone that turns, at an acute angle at the southeast end, to a due west strike and a north dip. This prong lies on the north side and around the sharp nose of a small south-eastward-trending and plunging anticline.

SOLUTION FEATURES

Solution played only a small part in the formation of the structure of the Trego or body. The Guttenberg strata, which in some other mines are considerably dissolved and thinned, here show nearly their full thicknesses, about 10 feet thick. Maximum observed thinning due to solution is therefore about 2 feet, which probably relaxed the structure slightly by minor slumping; it is not, by any means, large enough to have originated the structures. Dolomitization was unusually complete, for all rocks exposed in the ore body are completely dolomitized. Also, veins of late dolomite (fig. 67) that fill early fractures are a common feature in the mine but such veins are unusual in other ore bodies. This dolomitization apparently formed during the early stages of mineralization, as the veins of dolomite have been displaced by later faults filled with unsheared veins of ore.

The structures observed in the Trego mine apparently have been caused by regional tectonic forces. The visible solution-thinning was far less than would be needed to produce these folds and faults by slump, and the unusually complete dolomitization probably prevented solution-thinning in the hidden beds beneath the mine floor.

Third stage

The main characteristics of the third stage of structural development are:

1. Controlling folds have amplitudes of 20 to 100 feet and greater magnitudes; minor flexures are well formed and exhibit a regular and symmetrical pattern; locally the limbs of the folds dip as steeply as 10° or 15°.
2. Reverse faults are large, smooth-walled fractures, developed through many stratigraphic horizons; bedding-plane faults and their included veins of ore are common through the entire thickness of the ore body; combination of the two types of faults forms a fracture system that resembles an imbricate structure.
3. The incipient structures of the first and second stages are obscured.
4. Solution generally is important in many ore deposits, owing to numerous access fractures; it tends to accentuate the structure by producing slight slumping owing to thinning and shalification of the calcareous beds. Small solution sags and slump breccias are common and in a few mines tumbled breccias occur locally. Silicification and dolomitization are prominent types of alteration.

TECTONIC FEATURES

The Hoskins ore body (pl. 12) is typical of the arcuate ore bodies controlled by structures of the third stage in development. It lies on the flanks of a well-developed, elliptical, east-trending syncline that is 20 to 40 feet in amplitude, 1 mile long, and one-fourth mile wide. The ore body curves around the east nose of the fold. At the west end of the same syncline the Fields-Meloy mine (pl. 5) lies on its south limb and curves partly around the west nose. The Fields-Meloy ore body is controlled by a western extension of the same fracture system that controls the south limb of the Hoskins ore body. These two ore bodies form an elliptical pattern, which, if completed, would encircle the controlling syncline.

Most of the ore is deposited in the Decorah formation and lower part of the Prosser-cherty member of the Galena dolomite although, locally at least, some ore is in the Quimbys Mill member of the Platteville formation. The Hoskins ore body (pl. 12) is controlled by well-defined, smooth-walled, reverse faults and less prominent bedding-plane faults. Throughout the ore body the reverse faults show the third stage of development.

The controlling elliptical syncline is somewhat asymmetric and the anticline to the north has a greater amplitude than that to the south. It is split at its east end into two westward-plunging minor synclinal noses divided by a small west-plunging anticlinal nose.

Several well-defined subsidiary folds are present within the part of the syncline bounded by the Hoskins ore body. These minor folds are similar to those at the Trego mine, but are better defined. A syncline of arcuate pattern that occurs in the footwall side of the pitch zone along the entire length of the mine is the most important of these subsidiary folds. This arcuate syncline is traceable, from drill hole records west from the Hoskins mine, along the north and south limbs of the main fold to the west nose of the main fold where the two parts curve around and join again to form a complete ellipse. The small subsidiary folds in the central part of the Hoskins ore body are remarkably symmetrical in pattern. For example, the branches of the subsidiary low anticline in the center of the arcuate ore body converge and join to form a broad low anticlinal area in the east nose area. From this anticlinal area two peculiar anticlinal prongs extend into the ore body for a short distance from the Hoskins mine shaft toward the northwest and southwest and form a symmetrical pattern. The arcuate faults at the east end of the mine are doubly curved into arcuate sub-noses which conform to similar sub-noses in the folds. Other notable symmetrical patterns are visible as exhibited by all of the folds near the east nose of the mine (pl. 12). Such fold symmetry is probably only by regional tectonic forces acting through rocks whose strength and texture are very uniform.

Reverse faults are the best developed fractures of the Hoskins mine although bedding-plane faults are also numerous. The mineralized reverse faults, or pitches, branch and curve upward from the initial bedding-plane faults that lie either near the top of the Guttenberg or in the soft, plastic shale of the Spechts Ferry beneath. The pitches rise for 30 to 65 feet, extending upward into the cherty Prosser member of the Galena dolomite. They have an average dip of about 45 degrees. Their dips decrease again in a smooth curve near the top of the ore body and most of them die out or extend along a prominent bedding-plane as a bedding-plane fault. In a few places the reverse faults do not flatten near the mine roof but abruptly end against a prominent bedding plane in a manner similar to the step-like pitches of the Trego mine. If they have this form, generally some incipient inclined fractures enter the mine roof for a few feet above the junction point of the inclined faults and the topmost bedding-plane fault.

The inclined faults form a zone of two or three parallel, reverse faults of 2- to 4-foot displacement, dipping into the outside uplifted areas that bound the ore bodies. The total displacement of the parallel faults in each zone equals 6 or 8 feet, not including the drag of the beds.

Bedding-plane faults occur at favorable well defined bedding planes within the reverse fault zone. Most of these bedding-plane faults lie in the footwall side of the main pitch but gradually thin and die out as they extend into the central core area. Most of them contain thick veins of ore. An exception is at the base of the inclined fracture zone in the incompetent Guttenberg and Spechts Ferry members in which are the bedding-plane faults from which the reverse faults branch. Here, strong bedding-plane faults are in both the hanging wall and footwall of the main fault zone. Probably these bedding-plane faults were the initial fractures when the structures were formed. As the reverse fractures approach the bedding-plane faults from above they commonly flatten out in a smooth curve and join the initial bedding-plane faults at a low angle. Where two such bedding-plane faults were observed, one above the other, the inclined fractures flatten partly and join with the upper bedding-plane fault in the Guttenberg; but a weaker inclined fault branches and continues downward to join with the lower bedding-plane fault in the Spechts Ferry. The bedding-plane fault at the top of the Guttenberg can be traced for 120 feet in the drift to the East Hoskins ore body, where it then disappears into the roof, showing that the initial bedding-plane faults extend far out beyond the ore body itself.

In cross-section the reverse and bedding-plane faults of the third structural stage form a general rhombic pattern. Displacements of the reverse fault are dissipated along the bedding-plane faults both at the top and at the base of the fault zone in arcuate ore bodies. Few sharp bends or angles are seen in the inclined faults anywhere, as the projections were smoothed off during movement. The thickest veins of ore fill the bedding-plane faults at their junctions with the inclined faults, and these ore bands gradually thin as they extend away from the junctions. Most veins in reverse faults are thinner than those in the intersecting bedding-plane fractures.

Open vertical fractures along the central axial zone of the main syncline are apparently due to tension along the fold axis. Irregular, open normal faults dip in the opposite direction to the reverse faults in places along the footwall area.

SOLUTION AND ALTERATION FEATURES

The Guttenberg strata in the Hoskins mine are mostly silicified to a jasperoid that completely replaces the limestone, and faithfully retains most of its original texture and color. This silica is particularly abundant next to the major reverse fault zones, which suggests that the solutions that caused the silicification used these preexisting fractures as channels. Solution also caused 4 or 5 feet of thinning of the Decorah formation, but it appears to have been arrested early by replacement of the calcareous beds by silica. The Quimbys Mill is 9 to 11 feet thick in the area of the mine and therefore is almost unthinned even where mineralized. The total thinning by solution is small, it probably does not exceed 6 or 7 feet, much less than is necessary to account for the structure observed. The syncline in which the ore body lies has an amplitude of from 20 to 40 feet; and the inclined faults, and their drag folds, show vertical drops in the beds of from 15 to 20 feet. However, the observed thinning as a result of solution undoubtedly produced a little slump and accentuated the structure.

INTERPRETATION

The relations of the faults to the major and minor folds and also the type of displacements of the faults in the Hoskins mine are very similar to those in the Trego mine. However, the amount of displacement and the degree of folding are considerably greater, and a very symmetrical pattern is developed; the two limbs divided by the axis of the main syncline are nearly mirror images even to small details.

The cause of this structure is considered to be a regional tectonic force acting in the north-south direction. The widespread bedding-plane faults in the incompetent Guttenberg and Spechts Ferry members at the base of the Decorah formation are probably the fractures along which the initial movement occurred, and from which the reverse faults developed by branching upward.

The James mine (fig. 72), one of the largest known ore bodies in the district, and this ore body is also controlled by a fracture zone in the third stage of development. This fracture zone encloses the northeast nose of a large second-order anticlinal area, and dips inward toward it. Superimposed upon the larger structure is a series of smaller arcuate turns in the ore body and its fracture system; these turns are controlled by small transverse third-order folds. The swing of the fault zones is toward the central anticlinal area, where a third-order syncline crosses, and away from the central area, where a small anticline crosses the fracture zone.

The Federal mine (pl. 13) is an ore body similar to the Hoskins mine, but the west arcuate nose is the one that is fully developed. The fracture zone and the controlling third-order syncline are elliptical in pattern, and the low central anticlinal area has the form

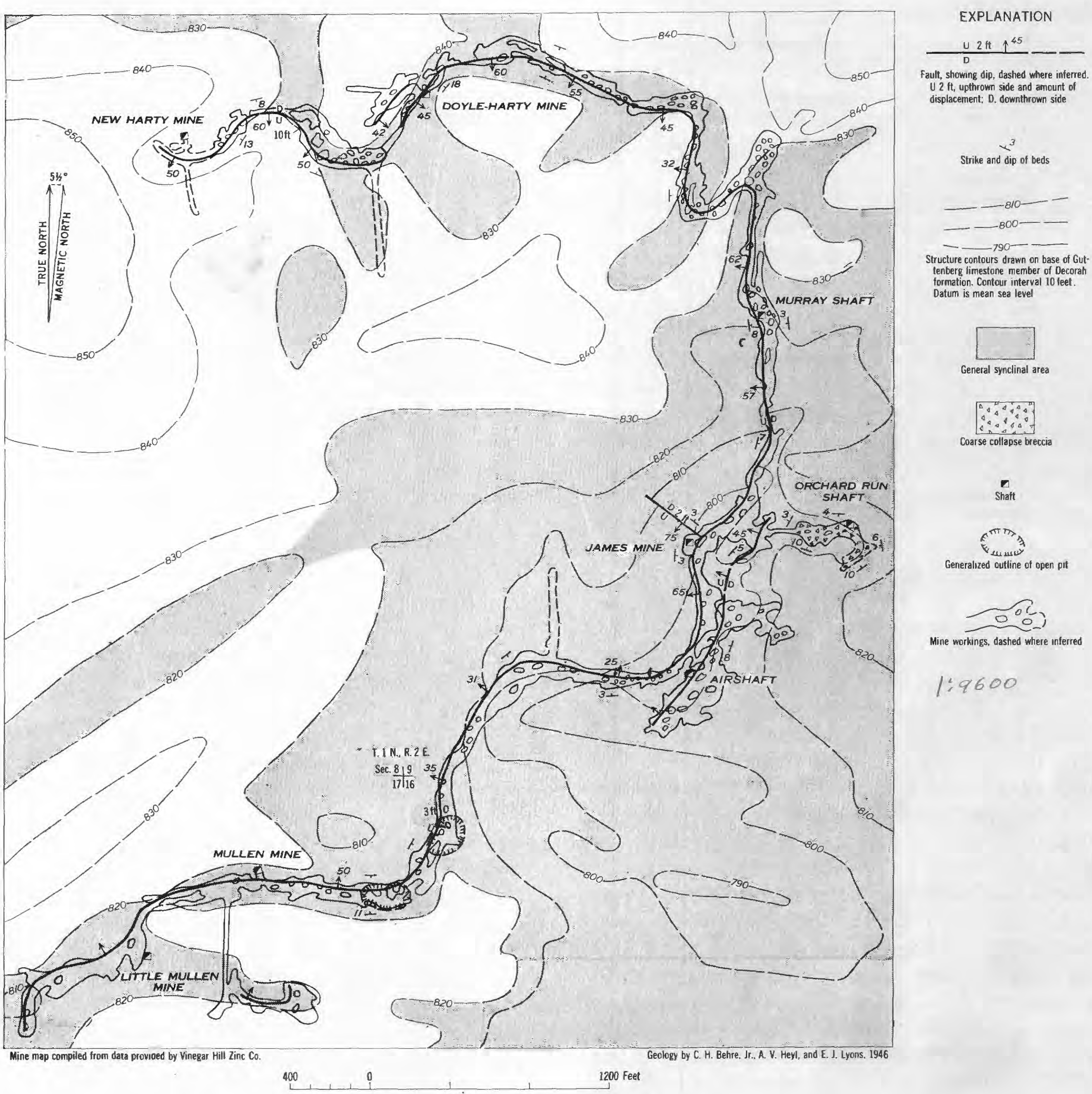


FIGURE 72.—Geologic map of the James mine.

of a very low dome, rather than a linear fold as in the Hoskins mine. The Decorah and Platteville have been thinnned by solution along the main fracture zone and slumping and opening of the fracture has resulted.

The Martin mine ore body (pl. 14) is also localized along a fracture zone that is in the third stage of structural development but is developed near the intersections of folds. The arcuate ore body is closed toward the north around the end of a northwest-trending syncline that plunges southeast. This third-order fold is crossed by a second-order, northeast-trending syncline (pl. 5) that lies just south of the mine. The two southward-extending limbs of the Martin fracture zone and ore body turn outward sharply at the ends and follow the north flank of the second-order syncline. The reverse faults in the Martin mine are particularly well developed and the unusually smooth, straight fault planes are grooved in places by strong vertical slickensides. Individual reverse faults show as much as 6 feet vertical displacement (pl. 14, section D–D').

The central anticlinal dome is higher than in many ore bodies and is cut by a series of strong northward-striking vertical tension joints along which the rock is strongly brecciated, perhaps in part as a result of solution and collapse, and is mineralized with low-grade zinc ore. Jasperoid and solution thinning are common along the main faults.

The Liberty mine (pl. 15) shows a somewhat less-developed, simpler arcuate structure; it is in the earlier part of the third stage of development. A vertical shear fault cuts the southwest part of the arcuate western part of the ore body. This fault is strongly grooved by horizontal slickensides and displaces the rocks on the southwest side 25 feet toward the southeast relative to those on the northeast side. The shear fault locally contains an unsheared vein of sulfides, but elsewhere it is filled with rock breccia and gouge. A northwestward prong of the ore body extends from the west arcuate part of the structure, and lies along the north side of the shear fault and consists of several horizontal veins in tensional bedding-plane openings possibly related to the shear fault or to solution slump along it.

The main part of the Monroe-Longhorn mine (pl. 16) is in a large arcuate ore body closed at the east end by a complex, trilobed, arcuate nose. The ore body lies along the flanks of the east end of a westward-plunging, third-order syncline, which, in turn, lies in a larger northeastward-trending, second-order, syncline that contains many similar, structures and ore bodies (pl. 5). The trilobed arcuate nose of the structure is similar in the Hoskins mine (pl. 12) except that three small synclinal and two anticlinal noses are present. The central synclinal nose is the best developed. The most notable feature of this structure is the fact that in the lower part of the mine the hanging wall reverse faults swing around the lobes; but the upper and footwall part of the fracture system continues directly north tangential to the synclinal lobes.

At the northeast corner of the Monroe-Longhorn mine a drift extends for several hundred feet into the small, northeast-trending, elliptical North Monroe ore body (pl. 16). This ore body is an example of the apparent ultimate pattern of the general east- and northeast-trending arcuate ore bodies.

The reverse faults in the North Monroe ore body form an elliptical pattern in the plan view, completely flanking the fold. These well-developed, inclined, smooth-walled faults rise from soft, shaly, bedding-plane partings in the so-called blue beds of the Ion member of the Decorah formation. The inclined faults dip at low angles outward on all sides into the bordering uplifted area. At the top of the faults, about 25 feet above their base, they flatten out along a prominent bedding plane and form a bedding-plane opening filled with a 1-foot vein of ore extending across the entire axial area. The reverse faults have a displacement of 6 inches to 1 foot; the rocks on the hanging wall sides of the faults apparently moved concentrically toward the central core zone.

Where the faults flatten out at their base in the lower beds of the Ion, they continue as a widespread bedding-plane fault which extends outward under the hanging walls for a considerable distance. At the southwest end of the ore body in the connecting drift, this bedding-plane fault can be traced outward for 140 feet, where the fault plane vanishes into the roof of the drift as the beds rise.

The usual subsidiary drag cyncline is present in the footwall area of the fault zones, and it also is elliptical in pattern. In the central core area, parallel to the larger synclinal axis, is a central subsidiary elliptical dome which is a structure similar to the interior subsidiary anticlines observed in other syncline ore bodies.

An irregular network of vertical fractures is in the mine roof above the uppermost bedding-plane fracture in the central area. These fractures are only in the beds above the roof, and appear to have been caused by a buckling upward to relieve the pressure as the surrounding rocks were compressed concentrically inward and upward.

The entire fracture pattern is that of an inverted elliptical saucer. The controlling syncline is somewhat asymmetric, for the south limb is steeper; which suggests that the structure was developed by active compressive forces in a N. 20° W. direction. The formation of the canoe-shaped syncline and its included elliptical ore body indicates that a N. 50° E. S. 50° W. forces were also active probably during the same general period, holding the ore body area under general compression from all sides and forming the elliptical structures. When the general compression increased in the central axial area, the forces that compressed the enclosing competent beds that overlie the fault zone reached a point where no further relief was possible by either bedding-plane faulting or along the inclined shear planes. Then the roof area was lifted somewhat vertically, as shown by the 1-foot thick top flat, and the final relief was in the vertical plane by a network of vertical fractures in a buckling action.

A partly developed, complex, elliptical structure, bordering the flanks of a much larger syncline that also includes several satellitic ore bodies, was mapped in the Wipet mine (pl. 17).

Arcuate and elliptical ore bodies that lie along northwest-trending synclines are much less common but where present are generally more oval than those found along northeast- and east-trending folds. Structurally, however, they are similar. Examples are the Frontier, Calvert, and Monmouth mines (pl. 5).

LINEAR ORE BODIES

Linear ore bodies are less abundant than arcuate ore bodies, but they are the most common type near Galena, Illinois and are present in many other parts of the district. Nearly all linear ore bodies flank synclines. Northwestward trending linear ore bodies are abundant, and east-trending linear ore bodies are common, but those trending northeastward are rare. They, like arcuate ore bodies, may be classified into three progressive stages of structural development; the first stage incipient structures are most common in the north part of the district, the second stage structures are mostly in the central part, and the third stage structures are present in the southern part.

First stage

TECTONIC FEATURES

The Dodgeville No. 1 mine (pl. 10) contains not only arcuate ore bodies but also northwest-trending linear ore bodies and controlling structures that lie transverse to the arcuate ore bodies. The linear ore bodies are regularly spaced across the synclinal parts of the arcuate ore bodies and in plan appear like rungs on a ladder. These transverse structures are controlled in one place by a small northwest-trending anticline, whereas northwest-trending synclines appear to be the controlling folds in the others.

The small narrow synclines in which the northwest-trending linear ore bodies lie in the Dodgeville mine have low amplitudes. For example, the syncline controlling the northwest-trending ore body just east of the main Dodgeville mine shaft shows an amplitude of only 3 feet from the west side to the central axis and a drop of 7 feet from the east side of the same axis. The width of this fold is probably not more than 300 feet; the known length is nearly 1,600 feet. The extremely elongate, attenuated pattern of this fold suggests a control other than by simple folding alone; which, in this example, is probably by earlier-formed vertical, shear joints that the synclinal axis of the fold follows and parallels. Joints or groups of joints may have acted as zones of weakness along which the folding and later bedding-plane faulting commenced, owing to compression by forces acting in the east and west directions. The ore bodies (more strictly "ore runs") and their main joints trend about N. 20° W.; this direction is very close to the average strike of the J_3 joints of the district. Possibly the east and west forces as they compressed the beds, selecting the zones of weakness developed by the earlier-formed joints, thus localized the folding. The northwesterly folds overlap the east-trending folds, plunging and arising over them.

All the northwesterly ore runs in the Dodgeville mine are controlled by a bedding-plane fault at or near the base of the Quimbys Mill member. This fault plane contains the principal ore vein; it is a plane similar to that which controls the easterly arcuate ore bodies except that most of the slickensides observed in these linear ore runs strike between east and N. 65° E. (fig. 68, diagram no. 2). However, some movement of the beds in the northwest direction along the faults is shown by a few slickensides in that directtion.

Several types of fractures other than bedding-plane faults are in the N. 20° W. trending ore runs. They are:

1. Low angle reverse faults or fault zones.
2. Strong vertical or steeply inclined straight fractures striking parallel to the ore runs.
3. Vertical or inclined straight fractures transverse to the ore run.
4. Breccias and network systems.

Low angle, northwest-trending, thrust or reverse faults are more common in the northwest-trending ore bodies than in the east- and northeast-trending ore bodies. Likewise, they are generally better developed, and can be traced along a greater length. Good examples can be observed in most of the northwest-trending ore bodies, traceable at least along part of their length. East-dipping faults are found in most northwest-trending ore bodies. A weaker, west-dipping fracture zone is also visible in a few places such as at the northwest end of the northwest-trending stope just east of the Dodgeville mine shaft. These fractures are reverse faults having displacements of a few inches up to about one foot. They are accompanied in most places by a parallel reverse fault drag syncline in the footwall area beneath the fault plane. The reverse fault in each place dips toward a relatively high anticlinal area.

The most incipient stage of reverse faulting was seen in several sets of inclined shears that dip toward the steeper limbs of a relatively strong anticlinal flexure that trends northwest. Where further developed one incipient shear plane was the fracture favored by the continued movements and this inclined shear became the fracture along which most of the movement occurred and formed a reverse fault. Most of the fault planes dip about 35 degrees, but some have an angle of dip as gentle as 10 degrees and a few as steep as 60 degrees. The faults tend to flatten in every place as they dip down toward the initial bedding-plane fault at the base of the Quimbys Mill until they are nearly horizontal and then join the bedding-plane fault.

Locally a few of these reverse faults are open, but most of the observed examples are tight, gouge-filled, shears, commonly strongly slickensided. Only small veins of marcasite and calcite can be observed in many of these fractures. A few of them are filled with ore, notably the reverse fault in the McGregor (pl. 10, section *D–D'*), and are therefore typical pitches. These relations suggest that many of the reverse faults were formed after the main bedding-plane faults had been filled with galena and sphalerite. Both types of reverse faults so closely resemble the reverse faults of other mines in all characteristics except degree of development that they are undoubtedly incipient fractures of this type.

Strong vertical or steeply inclined fractures that strike parallel to the ore runs are a prominent feature of the northwest-trending ore bodies. They are predominantly thin, vertical, joint-like fractures that form a closely spaced group within the northwest-trending ore runs. Many are not mineralized, but some that are wide have thin veins of calcite and marcasite, and less commonly sphalerite. They are probably of two types: (1) inclined fractures, a few feet long and locally distributed, that appear to be shear and tension fractures developed by movements along the bedding-plane faults; and (2) vertical fractures, many of which are over 100 feet long, that closely resemble vertical shear joints. The vertical fractures are traceable from the mine roof into its floor, where they continue downward into the McGregor member beneath the Quimbys Mill. The more important vertical fractures continue upward and are exposed in all the raises in the mine. A few of the strongest vertical fractures, particularly those containing mineralized veins, show vertical displacements of an inch or two. The vertical walls of one of these fractures are covered with horizontal slickensides, and thus some of them are shear faults of minor displacement. Some of these vertical fractures strike somewhat en echelon to the northwest-trending synclines and their accompanying workable ore bodies. This relationship suggests that the fractures may have formed independently of the synclines and their accompanying bedding-plane faults and the zone of vertical shear-joint fractures acted as an area of weakness along which the compressive forces folded the beds with greater ease than in unfractured rock.

At all ends of northwest-trending ore bodies, either at an intersection of ore bodies or where the ore becomes too lean to mine, the vertical fractures continue into the walls without deviation and they only slightly decrease in number. Although it could not be directly checked, these fractures probably continue for a considerable distance beyond the ends of the ore bodies. Possibly some of these fractures systems extend as much as 1,600 feet along their strike northwestward through the Dodgeville mine.

A few strong vertical and inclined fractures and minor shears strike transverse to the northwest-trending ore bodies. They closely parallel the axes of the east- and northeast-trending folds and their accompanying ore bodies, and therefore they are assigned a similar origin. Several similar well-developed, vertical cross-fractures are observed, near the axis of the main east-trending syncline in the north part of the mine. These fractures are fairly open, and apparently are the result of tension during folding along the east-trending synclinal axis. They are similar to tension fractures along the fold axes vein in the Trego and Hoskins mines.

INTERPRETATION

Premineral bedding-plane faults are as common and widespread in northwest-trending ore bodies as they are in east-trending ore bodies. In northwest-trending structures the east-west forces were dominant as shown by the slickensides. As these forces continued to act and maximum possible relief of stress along the horizontal plane was reached, then further relief was apparently easier in the vertical plane, which resulted in movements along inclined shear planes and the formation of small reverse faults. Some of the thrusting that produced the reverse faults in this mine was premineral, but some of it may have occurred during the later part of ore deposition. This relation is suggested by the presence of only late vein minerals in some of the fractures, such as late-deposited marcasite and calcite, and also by folding and fracturing of the ore-filled bedding-plane faults near reverse faults. The pattern and type of structures (for example, bedding-plane faults) involved, as well as the absence of marked solution-thinning and evidence of slump, strongly suggest an origin by regional tectonic forces. The close similarity of the force directions and structures in the mine to the district structures previously described under "structure" shows that the Dodgeville mine reflects in miniature the regional pattern and is therefore probably produced by the same tectonic forces.

The B. A. T. mine (pl. 18) illustrates a more advanced degree of development of the first structural stage. The north-trending central syncline is much larger and of greater amplitude than the northwest-trending syncline(s) in the Dodgeville No. 1 mine. The beds are much more brecciated near the bedding-plane fault, and pitches are locally developed not only in the Quimbys Mill but in the overlying Decorah as well. All of these beds have been markedly thinned by solution in the two ore bodies flanking the central syncline.

The New Birkett mine (pl. 19) is an example of a linear, northwest-trending ore body controlled by a structure that shows development that is transitional between the first and second stages. The ore body is fairly narrow straight and treads about N. 10° W., and lying along the approximate axis of a parallel-trending linear syncline about 400 feet in width. This syncline is apparently a small northward branch of a much larger, second-order syncline. The minor fold has a maximum amplitude of 20 feet.

A comparison of this ore body (pl. 19) with any of the synclinal, northwest-trending ore runs in the Dodgeville mine (pl. 10) shows similarities in trend, pattern, and general folding. There are certain differences however: (1) the amplitude of the controlling syncline is greater than at Dodgeville; (2) the smaller folds are better developed in the New Birkett mine; (3) the New Birkett ore body is wider and in places it has two parallel ore runs with a central lean area; and (4) a definite tendency toward a symmetrical structure is developed in the New Birkett that consists of three north-trending parallel minor folds within and along the larger main syncline. The central fold is a relatively barren anticline, and the outside folds are synclines along which are concentrations of ore.

Transverse to the ore body and main structural trend is a series of northeast-trending cross folds. Three minor cross-anticlines and four general cross-synclines are indicated. These cross structures seem to have had little effect on the ore localization.

The main controlling fracture in the New Birkett mine is a bedding-plane fault in the soft, plastic Spechts Ferry shale member. Above and below this fault the overlying Guttenberg and underlying Quimbys Mill members have been sheared, brecciated, and displaced by numerous subsidiary bedding-plane faults. The overlying competent beds of the upper part of the Decorah and lower part of the Galena have been little deformed. The main bedding-plane fault extends the full length of the mine and vanishes into the mine walls in all directions, so its full extent could not be determined.

The inclined and vertical fractures are better developed than in the Dodgeville mine ore body. A well-developed zone of open, locally mineralized, vertical fractures strikes parallel to the ore body, particularly along its east edge. These fractures are similar to those that parallel the northwest-trending ore bodies in the Dodgeville mine, but everywhere they are better defined and commonly show some vertical displacement.

Reverse faults of small displacement occur in the mine. Most of them branch at a low angle from the bedding-plane fault and steepen as they rise from the Spechts Ferry shale member. The most conspicuous of these faults parallels the central anticline along its east limb and passes through the north half of the ore body. Many of these reverse faults are in the east syncline and dip toward the general anticlinal area to the east. However, in no part of the mine have these fractures developed into typical pitches.

The ore is disseminated in well-formed crystals of sphalerite in favorable beds and brecciated areas near the base of the Guttenberg, in the Spechts Ferry, and in the top of the Quimbys Mill members. Some typical replacement veins of ore are locally along bedding planes, below, and laterally at the ends of the veins

Solution, and its accompanying shalification and mass flowage, is a conspicuous feature of the mine, particularly near the main bedding-plane fault. There, large areas of both Guttenberg and Quimbys Mill have been fractured into coarse fragments, between which the shaly layers and shaly residue of the partly dissolved limy layers have been squeezed, recementing them into solid rock. This type of flowage with very few cavities could have occurred only under considerable pressure. Shalified rock is only in brecciated areas and along fractures and fracture zones. Elsewhere the rocks are nearly unaltered and retain almost their full thickness. The average thickness of the Guttenberg after solution and plastic flowage is about 9 feet in this mine.

Second and third stages

TECTONIC FEATURES

Different parts of the Graham-Ginte mine (pl. 20) serve as examples of a linear ore body in the second and third stages of development.

The ore body lies within a northwest-trending complex structure that is essentially a syncline. The probable width of this fold is about 1,400 feet, and it has an amplitude of about 35 feet. The ore body follows closely the axial area of the syncline.

Numerous smaller folds occur within the ore body both parallel and transverse to it. The main fold and its subsidiary parallel flexures are crossed by easterly trending folds (pl. 20).

The minor folds that are within and parallel to the ore body are particularly well defined in the north part of the mine, and as in the New Birkett mine, three parallel folds extend through the full length of the ore body. They consist of a low central anticline with parallel synclines on each side. Ore is more abundant in the synclinal areas than in the central anticlinal area which is unmineralized in part. Locally, these folds have been further complicated by many still smaller flexures, faults, and crumples although the usual minor fold relationship is distinguishable throughout. In the upper stopes of the mine where the beds are thick and competent the only fold observed is a simple, shallow syncline along the ore body. Near the central part of the mine (pl. 20, section *D–D′*) these three folds broaden and diminish in amplitude; the axes diverge southward, so that the central anticline and the eastern syncline are east of the mine workings from the central part southward and have been traced by the drilling for some distance south of the mine. South of the Ginte shaft mining has continued only along the western syncline, which becomes nearly obscured by numerous small faults and subsidiary flexures.

The Graham-Ginte ore body is controlled by a zone of many bedding-plane faults, reverse faults, and fractures that resemble shear joints, and a few normal faults. The faulting has been accompanied by shearing, abundant minor fracturing, and brecciation; in addition considerable solution thinning of the calcareous beds caused widespread shalification, slump, and plastic flowage in the more incompetent beds.

The structures in the north half, or Graham part of the mine, are in the third stage of structural development, but those in the south half or Ginte part are still in the second stage. In the north half reverse faults are the most conspicuous controlling fractures and are accompanied by many bedding-plane faults and fractures. In the south half, or Ginte part of the mine, bedding-plane faults are the main controlling fractures and reverse faults are lesser features.

The Ginte part of the mine will be considered first, because here the fracture system is in the second stage of structural development. The least development of the controlling fractures is seen in the area north from the Ginte shaft for about 260 feet, on the gentle north-dipping limb of a transverse anticline whose axis passes south of the shaft. The main controlling fracture is an ore-filled bedding-plane fault that passes horizontally along a shaly parting in the lower beds of the Ion dolomite member of the Decorah formation. This fault plane (pl. 20, section *D–D′*) extends throughout that part of the mine, and is widest along the west edge of the ore body. Near the west mine wall the bedding-plane fault turns down, joins a reverse fault that dips westward at about 15° and penetrates the Guttenberg, below where it flattens out again along a shaly bedding plane and disappears into the west wall. In some places this step-like fault continues down into the mine floor, toward the incompetent Spechts Ferry member. The displacement of the reverse fault is only 6 to 12 inches although considerable drag is present. The bedding-plane fault in the Ion extends to about the east wall of the mine, where it dies out. East of the inclined fault plane is a zone of well-developed vertical fractures that strike parallel to the ore body. A few show very small vertical displacements. They are nearly smooth-walled and many are hundreds of feet long. These fractures may possibly be an earlier-formed J_3 shear joint zone of weakness along which the later structures were localized.

Southward toward the transverse anticlinal axis near the Ginte shaft the structure becomes better developed and more complex (pl. 20, section *E–E′*).

The entire southern end of the mine is a complex system of subsidiary structures. The same zone of prominent vertical fractures is in the competent beds in the roof of the central part. The fractures are well developed here, and where they cross the incompetent beds near the Decorah-Platteville contact, many of them curve into inclined fractures that are either normal or reverse faults. A remarkable stuctural feature is a faulted anticlinal horst nearly restricted to these incompetent beds that parallels the main west-dipping reverse fault on the east (pl. 20, section *E–E′*). This horst was traced for 360 feet in the southern part of the mine (pl. 20). The horst appears to have been formed from a sharp anticlinal flexure in which lateral compression was localized by the zone of weakness formed by the two strong vertical fractures in the competent beds above. As the incompetent beds were bowed up beneath the fractures, the crest of the fold was forced against the more resistant beds above. The incompetent rocks along the anticlinal axis were squeezed away from the axis by plastic flowage as the fold pushed upward against the resistant rocks. Solution was more active in this crest area owing to the relatively high pressures. As the calcareous layers along the axis were dissolved and the shaly residues were squeezed aside, the central mass was forced upward until the overlying beds broke along the sides of the arch and two normal faults were formed dipping away on each side from the central axial area. The beds in the axial segment moved up along these planes of movement until the central horst block was forced up about 10 feet. The normal Guttenberg thickness of about 12 feet was reduced along the axis to as little as 2 feet by solution and squeezing away of the shaly residues. The competent beds above the horst were bowed up somewhat but, except for minor faulting, otherwise resisted the pressure. Other less developed structures of this type were mapped (pl. 20, east half of section *E–E′* and central area of section *C–C′*). From left to right in section *C–C′* three structures of this type can be seen in different stages of growth.

In the east part of the mine area illustrated in section *E–E′* (pl. 20), bedding-plane compression took place in the Spechts Ferry and along the shaly partings in the Guttenberg limestone member above, causing a lateral shortening of 13 feet. The limestone layers of these rocks in this area of extreme shortening have been nearly completely dissolved by ore solutions. The beds have flowed plastically, forming minor recumbent and isoclinal folds (fig. 39 and pl. 20, section E–E′). Although the Guttenberg member if uncontorted would be about 4 feet thick, it has been closely folded, squeezed and compressed laterally into the smaller volume and is locally about 7 feet thick. Similar, but lesser, foreshortening has occurred in the more competent Ion member above, as shown by small thrust faults and minor flexures along the contact between the competent and incompetent beds. Other evidence of intense lateral compression is the presence of the many fractures that are so tight that practically no openings were available for ore deposition.

A good illustration of the third stage of fracture development in linear ore bodies is the north half of the mine, commencing about 260 feet north of the Ginte shaft. Bedding-plane faults are important structures here, but they are subordinate to the reverse faults. Reverse faults are the principal controlling fractures, in places rising 150 feet to the base of the soil. They form zones of outward-dipping reverse faults along the eastern and western walls of the mine. The east-dipping pitches are best developed in this north part of the mine and have been mined farther to the north than the west-dipping fault system. The greatest development of these faults is on the south-dipping limb of the tranverse syncline at the south end of the Graham part of the mine.

The reverse faults are smooth-walled, relatively tight fractures that commence in the incompetent Spechts Ferry shale member at the base of the Decorah formation. These reverse faults branch at a low-angle from bedding-plane faults in the shale and curve sharply upward to an average dip of 60°. They may flatten locally along bedding-planes; but most of the faults rise as smooth-walled fractures of increasing steepness, until they die out either as nearly vertical fractures or at intersections with bedding-plane faults at the mine roof. Several of the faults reach the surface, more than 150 feet above their base, where their dips have steepened to about 70° or 80°. The fault planes are commonly strongly slickensided and show displacements of 3 to 7 feet near their bases. Each reverse fault zone consists of 2 to 5 parallel faults, and the total displacement of the zone may total as much as 12 feet. The inner, weaker faults tend to die out above first; and in the uppermost level of the mine only the outermost and strongest faults continue; their displacements have diminished by several feet. The entire structure consists of a small ramp-type graben bounded by outward-dipping reverse fault zones.

Ore-filled flats extend into the central core area along prominent bedding-planes. These flats show gouge, brecciation, and minor shear fractures that indicate they are bedding-plane faults.

The vertical fractures in the central core are less numerous and weaker in the Graham part of the ore body, but some of these fractures show as much as 4 feet of vertical displacement. They appear to have acted as tension fractures parallel to the central anticline along which the stresses from compressive forces were relieved. Some open normal faults that extend downward from the pitches acted as tension and adjustment planes for the reverse faults.

The reverse fault zones on each side overlie a subsidiary northwest-trending syncline, and the usual subsidiary anticline is in the central area between them. The synclines apparently were formed by foreshortening and drag of the beds along the main reverse faults during displacement, and then later were accentuated by slump from solution. The central anticline dies out above; so in the upper stopes the two synclines join to form one gentle basin.

At the south end of this part of the mine is a south-pitching arcuate reverse fault (pl. 20, plan view and sections *B–B′*, *C–C′* and *F–F′*). This fault connects inner reverse faults on both sides of the mine and swings around forming an arcuate south-dipping fault. At its base, it joins the bedding-plane fault in the Spechts Ferry. Disregarding the other fractures, this arcuate fault is very similar to those observed in arcuate ore bodies elsewhere and evidently is of similar origin. At its southern end this fault dips into the north limb of the transverse anticline which is developed near the Ginte shaft. This anticline and the arcuate fault are probably the result of forces acting parallel to a N. 80° E. direction interacting with others in a N. 10° W. direction.

SOLUTION FEATURES

Solution was a more important factor in the development of the structure of this ore body than many others. The Guttenberg member in a few places has been thinned from its original 12 feet to as little as 2 feet. However, the average thickness in the ore body of the altered Guttenberg is about 7 feet, which shows that the thinning by solution is about 5 feet in this member. Test drill holes put down in the mine floor under the supervision of H. B. Willman (oral communication, January 1945) show that a corresponding thinning of the Quimbys Mill has occurred in places;

so that the total solution-thinning is several feet more. Commonly the thinning in the Guttenberg does not overlie the thinning in the Quimbys Mill. Solution-thinning has accentuated the structures by sagging and slumping, and has also provided room for the tectonic flexing and foreshortening of the beds.

INTERPRETATION, OTHER LINEAR ORE BODIES

A northwest-trending linear ore body remarkable because of the extremely straight controlling fracture system of reverse faults and central vertical joints is in the Pittsburg-Benton mine (pl. 21).

East-trending linear ore bodies have been found in several places throughout the district. These ore bodies are structurally identical with the linear ore bodies of other trends. The best example is the line of eastward-trending ore bodies near New Diggings, Wis., which extends from the Champion mine at the west end (NE¼ sec. 27, T. 1 N., R. 1 E.) and to the Thompson mine at the east and (pl. 5). The total known length of this line of linear ore bodies is a little over 3 miles.

Several of these linear, east-trending ore bodies are located in the upper and middle part of the Galena dolomite, rather than in the more usual lower part of the Galena dolomite, and in the Decorah and Platteville formations. They are classified as "Middle Run" (Willman, Reynolds, Herbert, 1946) ore bodies. Most mines in such ore bodies were inaccessible. However, the Hazel Green mine, which is of this type, (pl. 21) was briefly accessible. Here the main workings are in the upper part of the Prosser cherty member. The north- and south-dipping reverse faults on opposite sides of the ore body join at the mine roof in a vertical fracture that is exposed along the entire length of the mine. The vertical fracture continues to the surface, where its location is marked by an east-trending line of lead pits.

The ore is in veins along the reverse faults, forming typical pitches; it also occurs in the central area between the two reverse faults in an irregular, ore-cemented solution breccia. One of the uncommon, ore-lined caves was found in this mine, apparently along a northeastward-trending vertical fracture that has been enlarged by solution. This cave was lined with crytallized sphalerite, from which projected sphalerite stalactitic forms. Although now completely removed, it was described by Bain (1906, p. 86–87).

The Durango Drybone mine (pl. 21) is along the north section line in the northwest corner of the NE¼NE¼ sec. 1, T. 89 N., R. 1 E., on the south side of the Middle Fork of the Little Maquoketa River, a quarter of a mile southwest of Durango, Iowa. This mine was worked for many years for smithsonite and galena. The workings include an open cut 80 feet wide and 300 feet long, stopes in the walls of the cut and beneath it. It is a part of the old Timber lead range that extends for several miles and is one of the longest and richest in the Dubuque area. While in operation the mine was described by Leonard (1896, p. 45–48).

The ore body is only in the upper part of the Prosser cherty member and the lower part of the Stewartville massive member of the Galena dolomite, and is mainly in the latter member. The main ore-bearing zone is about 140 feet above the base of the Decorah formation.

The ore body trends about N. 85° W. and is bordered on the north and south side by outward-dipping mineralized reverse faults that have 2- to 4-foot displacements. These faults dip at about 45° to 65° and were cut at depth by drill holes. However, sulfide concentration at depth was very lean. Drilling results indicated that a shallow syncline extends along and beneath the ore body; the reverse faults dip toward uplifted areas to the north and south.

A series of straight, smooth-walled vertical fractures that strike N. 70° W. are in the central core area of the ore body between the opposing faults. Transverse to the ore body, another series of vertical fractures strike about N. 35° E., many of which are faults of small displacement. Both fracture sets apparently are shear joints along which some adjustment of the beds took place owing to later deformation that produced the main ore-controlling fractures. The N. 70° W. fractures apparently belong to the J_1 joint group, and the N. 35° E. set apparently to the J_2 joint group.

The basal beds of the Decorah formation are not thinned by solution; thus, solution slump could not have caused this structure.

The opened bedding-planes and reverse faults in the ore body contain veins of smithsonite, probably mostly a direct replacement of the original zinc mineral, sphalerite. Brecciation is common in the rocks of the ore body, particularly near the reverse faults, and most of these breccias are mineralized.

GASH-VEIN, JOINT-CONTROLLED ORE BODIES

This type of ore body was described in detail by earlier geologists (Percival, 1855, p. 31–69; 1856, p. 27–44; Hall and Whitney, 1858, p. 437–462; 1862, p. 235–255; Chamberlin, 1882, p. 451–468; Leonard, 1896, p. 36–43; Calvin and Bain, 1899, p. 510–516) at times when many more gash-vein ore bodies were accessible for observation. Because most of them are now inaccessible, the gash-vein deposits will be described in less detail.

The gash-vein deposits are only in the Galena dolomite. The deposits are in and along remarkably long straight vertical joints some of which are traceable by shallow mine workings for 1 to 2 miles. The principal minerals in these deposits are galena, pyrite, marcasite (or limonite where oxidized), calcite, and sphalerite (or smithsonite where oxidized). Sphalerite is the most abundant mineral in several places, commonly in the western part of the district; however, chalcopyrite and its oxidation products are the principal minerals of the deposits in a few locations (as in the area east of Mineral Point, Wis.). The vein minerals chiefly line the walls of the joints forming discontinuous gash veins; are ~~also deposited~~ in brecciated and party dissolved porous zones of rock, or "openings", in favorable beds ~~along the joints; and~~ also, where weathered, are found as loose rubble within the joints. The openings are bean-pod-shaped and contain horizontal vein and solution-breccia ore bodies whose long dimensions parallel the strike of the joints that they follow. Openings in strata above the water table may also be changed to clay-filled caves or partly dissolved, weathered, porous rock. Ore bodies are spaced irregularly and discontinuously along the lengths of the joints and form a series of pod-like masses in a nearly horizontal line. The ore minerals are deposited also in pinching and swelling gash-veins within many of the openings. Several openings, or lines of openings, may be successively below each other along the same joint in favorable beds. Thin gash-veins may connect the openings vertically and laterally along the joint, but only some of the veins between openings contain ore rich enough to be mined at a profit. The openings generally range between 4 and 20 feet in width, 5 and 20 feet in height, and from a few feet to several hundred feet in length. Openings are found at several stratigraphic horizons in the Galena dolomite. The stratigraphic horizons in which the openings lie are consistently the same within local areas of the district, and possibly some of the horizons favorable in one part of the district may also be favorable in other areas. However, this relationship has not as yet been fully verified. Although all the known openings may be mineralized throughout small areas, openings at one horizon in certain parts of these areas may consistently contain more ore than those in other parts. For example, such openings occur along the joints at several recognized stratigraphic horizons in the Prosser cherty member of the Galena dolomite in the Beetown area (pl. 7 and Heyl, Lyons, and Theiler, 1952).

These are:

Description	*Average depth in feet below the top of the Prosser cherty member*		
	Roof of opening		*Floor of opening*
First, or 12-foot opening (roof at about the top of the highest chert layers)	0	to	12
Second, or 32-foot, or False opening (not commonly ore bearing)	44	to	52
Third, or 65-foot opening	77	to	95
Fourth opening (just above the base of the Prosser)	105	to	110

The first or 12-foot opening was the largest producer of lead ore in the central and eastern parts of the Beetown area in the past although ore was found also in the other three openings in these parts of the area. Lead ore was successfully mined in all four openings in the western part of the area, along Rattlesnake Creek, but the 65-foot opening was by far the largest, most abundantly mineralized, and most extensively mined at this locality.

The gash-vein deposits occur in single isolated joints; but in many localities they occupy a group of parallel joints and, in some places, these groups are arranged in echelon. Commonly, master joints that are more strongly mineralized occur at fairly regular intervals several hundred feet apart; between the principal joints are many smaller joints.

The joints that contain the most abundant gash-vein deposits are in the J_1 group that strike slightly south of east throughout the district. Other ore-bearing joints strike, in the order of their abundance, northwesterly, northeasterly, and northerly. Most areas of heavily mineralized gash-vein deposits contain complex systems of joints in all of these directions (pls. 6, 7). The gash-vein deposits along the easterly joints, which are more open fractures, contain most of the openings. In contrast, the less-open northwesterly, northeasterly, and northerly joints more commonly contain only vertical gash veins. These veins of galena range from half an inch to 4 inches wide. Solution was active along the mineralized joints at the time of ore deposition. The ore solutions have dissolved and partly disintegrated the dolomitic wall rocks, particularly in favorable beds or groups of beds that were slightly brecciated or more porous, forming solution breccias, sanded dolomite and, in places, solution cavities. Rocks within openings below water table are commonly unbroken but are full of small solution cavities and curved tubes, and resemble a sponge. In a few openings the rocks are composed of angular and sub-rounded fragments. Sulfides of iron, lead, copper, and zinc cement and fill the cavities and rock fragments. Some breccias of angular fragments alone are in the walls of fractures along which movements have occurred; these appear to be tectonic breccias rather than solution breccias. The altered dolomitic wall rocks of the openings have disintegrated to a dolomite sand by weathering where the water table was lowered past the veins and openings.

The minerals are deposited in the gash-vein deposits as follows:

1. Thin gash veins completely filling the smaller joints and associated fractures.
2. Crusts of coarse crystals that line the two fracture walls of joints and openings, where they form large vugs.
3. Crystals and crystal clusters deposited along the joints, and between the rock fragments of tectonic and solution breccias.
4. Replacements of the wall rocks of the joints and openings.
5. Fallen and broken masses of ore minerals in loose dolomitic sand and fragments of rock, where the rock has been weathered at or above water table.

Where weathered, the wall rock of the veins is loose, nearly disintegrated dolomite which commonly is still in place. The original bedding planes can be traced from the solid rock walls continuously through the soft sanded rock to the central veins. Disintegrated deposits (no. 5 in the list above) occur where weathering has advanced so far that the entire mass collapsed into a loose pile of rock and ore. Where both lead and zinc minerals are in the same joint they may be deposited in separate parts of the joints and openings. Similarly the deposits of these minerals may be in certain openings or parts of openings; whereas neighboring openings may be completely barren. For example, lead deposits may be in the same vertical joint as zinc deposits, one above the other. Along the joint galena occurs above and the sphalerite below in different openings which by structural characteristics are scarcely distinguishable. The Rodham mine is in the largest known ore body of the gash-vein type; it is in the N½ sec. 25, T. 2 N., R. 2 E., 4 miles northeast of Shullsburg, Wis. Both lead and zinc sulfides occur in this mine, but galena is more abundant in the upper parts of the same joints that contain the sphalerite below. Vertical intersecting joints whose strikes are easterly, northeasterly, and northwesterly, control this ore body. At the intersections of these joints vertical chimneys that contained rich ore were followed upward. The ore body is restricted to the beds of the Prosser cherty member of the Galena dolomite. The Rodham ore body was mined by large-scale mining methods, unlike most of the other gash-vein deposits.

A similar ore body of this mineralized joint type is that of the New Mulcahy mine, 1 mile west of Shullsburg, Wis., in the south part of the SE¼NE¼ sec. 9, T. 1 N., R. 2 E. (pl. 22). The main fracture control in this small ore body is a series of parallel vertical, or steeply inclined shear joints of the J_2 group. These joints, striking about N. 20° E., have vertical mineralized veins along them and form a general opening in the gray beds of the Ion member of the Decorah formation. The ore in this part of the deposit is mainly sphalerite and marcasite that is deposited as veins along the joints, as small subsidiary wall-rock veins, and as irregular fracture and solution-cavity fillings in partly dissolved and sanded dolomite, forming a deposit locally known as a "brangle." Along the same joints in the Prosser member above, sphalerite and marcasite are uncommon, and galena is the dominant mineral, occurring in simple gash-veins along the joints. Small flexures occur in the beds and these trend parallel to the N. 20° E. joints. Some of the joints have a very small vertical displacement along them, mostly indicated by a slight drag in the beds near the joints.

PLACER AND RESIDUAL DEPOSITS

Placer and residual deposits of galena and limonite, and less commonly smithsonite and barite are common locally throughout the district.

Galena, generally coated with lead carbonate, is fairly common as residual masses lying on the present rock surface. The coating of lead carbonate preserves the original core of galena, preventing its disintegration by weathering and the action of surface waters.

This residual, or "float" galena, is widespread in areas of lead deposits, where it is scattered over the bedrock surface and in the soil. The galena accumulates in small pits and cracks in the bedrock surface, and particularly in open clay-filled joints. It is commonly mixed with residual clays and fragments of chert nodules from the Prosser cherty member of the Galena dolomite. Residual galena was so abundant in certain areas that it was mined to advantage by the primitive, shallow-shaft system of the early lead mining days, particularly where the weathering had penetrated to just below a well-developed flat or zone of openings of galena (Percival, 1835, p. 41).

The residual galena tends to creep down hill with the soil; so eventually it reaches the valleys and is carried along by the streams, forming placers. This "float lead" guided early prospectors in their search for ore-bearing joints.

The "float lead" carried downhill by creep, plus that released by stream erosion, has accumulated in typical placer deposits with the stream gravels in depressions and cracks in stream beds. The placer deposits were mined locally, as along the small stream that crosses the N½SE¼SE¼ sec. 28, T. 2 N., R. 1 E. (pl. 3). However, many of these placers seem to have been ignored by the early miners except as clues to the location of mineralized joints.

Two opencuts have been made in recent years to excavate sulfide ore bodies from bedrock underlying stream gravel deposits. One is the Meekers Grove open cut (pl. 3) in the SE¼SW¼ sec. 16, T. 2 N., R. 1 E.; and the other is west of Linden, Wis., in the NW¼ NW¼ sec. 8, T. 5 N., R. 2 E. The stream gravels are filled with scattered lumps of galena at both localities, and the underlying ore bodies are not particularly rich in lead; so the deposits in the gravels are very probably true placers, rather than residual deposits. Abundant smithsonite in large lumps is mixed with the galena and stream gravels at the Linden locality. As the underlying zinc deposit is unaltered sulfide below the water table, this smithsonite also appears to be a placer deposit whose source is upstream. It is not known if placers worth mining of either of these two types occur, but they are a little-known, potential source of ore that may be widespread in the highly mineralized areas.

OCCURRENCES AND TEXTURES OF THE ORES IN THE FORMATIONS OF MIDDLE ORDOVICIAN AGE

The occurrences of ore differ according to the type of structures with which the deposits are associated and the type of rock in which the deposition took place. The main occurrences are as follows:

1. Vein fillings and replacement veins along fractures and bedding planes.
2. Cavity fillings in fault breccias and fractured zones.
3. Cavity fillings in solution breccias.
4. Disseminations by replacement and impregnation in favorable beds, particularly shaly horizons.

The ores show several varieties of texture. These textures are in part dependent upon the types of deposition listed above, and in part ore-bearing solutions themselves. The textures of the ores are as follow:

1. Banded veins with symmetrical or asymmetrical banding.
2. Solid veins consisting of only one mineral.
3. Individual, well-formed crystals replacing the host rock.
4. Individual, well-formed crystals impregnating the host rock.
5. Crystals formed interstitially to the rock, without notable replacement of the rock grains.
6. Coarse crystals lining open cavities.
7. Reniform, colloform, nodular, and stalactitic masses.
8. Replacements of fossils.
9. Pseudomorphic replacements of earlier-formed minerals.

These textures will be discussed below under the several occurrences of ore.

VEIN FILLINGS AND REPLACEMENT VEINS ALONG FRACTURES AND BEDDING PLANES

Veins are characteristic of all the pitches and flats and the vertical mineralized joints. Veins are the most abundant occurrence of ore in the district.

The ores are most commonly deposited as symmetrically banded veins filling fractures (fig. 52), although asymmetrically banded veins are also common. The banding is due to a regular paragenetic order of deposition, which commences at the fracture walls and fills the veins toward the center. A thin film of pyrite (fig. 52) lies against each vein wall in most of the ore bodies. This film has an irregular boundary against the rock owing to the partial replacement of the rock walls by pyrite. Replacement of pyrite beneath the film on the rock walls continues into the wall for an inch or more gradually decreasing in quantity. In somewhat fractured or porous wall rock this pyrite replacement may include all the rock for 1 to 20 feet bordering the veins. Locally the pyrite deposition was excessive and large nodular masses of radiating cubic crystals or groups of elongated cubes project from the thin film toward the vein center (fig. 55).

Commonly, next toward the center of the vein, a band of marcasite lies adjacent to the pyrite film. Many local coarse crystallizations and concentric, fibrous, globular masses of marcasite project from the band toward the central vein area. Next toward the center of the vein from these bands of pyrite and marcasite, sphalerite and wurtzite (?) are most commonly deposited (fig. 52). The zinc sufide is in the form of bladed and columnar crystals growing toward the vein center from both walls, or it is in botryoidal crystalline masses radiating from common centers. These botryoidal masses are particularly typical of open fractures, where the presence of the central opening permits such forms to reach their fullest development. Concentric fractures in these reniform masses tend to divide them into several successive shells separating iron-lean zinc sulfide from iron-rich zinc sulfide. The fractures are filled by a fine-grained porous band or by microcrystals of iron sulfide. The primary zinc sulfide was tested metallographically; it is isometric but has the habit and bladed form of wurtzite. Behre states (Bastin and others, 1939, p. 115) that some of the crystals show extinction and locally there is a suggestion of aggregate polarization.

Marcasite in botryoidal masses and well-defined crystals of the cockscomb variety occurs within the bladed sphalerite. Galena in elongated crystalline masses, skeletal crystals, and graphic intergrowths is commonly present. The crystals commonly extend beyond the sphalerite crystals into the central opening of the vein zone where, free of the enclosing sphalerite, they formed well-shaped crystals (fig. 51).

Several minerals, generally in banded symmetrical layers, may be found in the remaining central opening. They are mainly crystallized marcasite, pyrite, galena, late sphalerite, calcite, and less commonly barite, chalcopyrite, and millerite. In most veins only one or two of these minerals are present.

If an open vug occurs, coarse well-formed crystals of the later deposited minerals line the central space, forming crystal-lined cavities within the earlier deposited minerals. The cavities represent the remaining unfilled part of the original open fracture. Many of the cavities are small, 1 inch to a few inches wide, lenticular and elongated parallel to the fracture. Locally the crystal cavities are quite large, being a foot or so wide and as much as 30 to 100 feet long. Elongated, projecting, nodular masses, a few of which are shaped like stalactites, line a few vugs. They are composed of radiating crystal aggregates of sphalerite, marcasite, pyrite, or galena. Some masses have a central tube passing through the entire length, but others are without a central opening, and have a core of pyrite or galena. The stalactitic forms of sphalerite, galena, and marcasite are several inches in diameter, and are composed of coarse radiating aggregates. Some pyrite and marcasite stalactitic forms are only a half to a quarter of an inch in diameter, and their outside surfaces are nearly smooth (fig. 56). These stalactitic forms may be pencillike with sharp bends and turns, or they may be steeply conical, tapering nearly to a point, through the center of which passes the tube. It should be noted that they point upward into the cavity in most vugs where they have been observed in place (written communication, Paul Herbert, Jr., 1946; see also Behre, Scott, and Banfield, 1937, p. 804–805).

The symmetrical banding of most of the ores deposited as veins in the pitches and flats is apparently due to the regular sequence of deposition by the several minerals that the ore-bearing solutions deposited in open cavities of these fractures. The gouge and smaller rock fragments within these minor faults were replaced by sulfides.

In the Dodgeville area most of the ore is in veins along bedding-plane faults. The central parts of these veins have well-developed symmetrical bands that grade into disseminated sphalerite crystals above, below and laterally. Laterally toward the edges of the horizontal veins the ore loses its symmetrical banding and grades into a replacement vein consisting of a thin central solid ore area that contains two opposing sphalerite bands and a wide border of disseminated sphalerite crystals in the wall rock above and below the central bands. The borders grade into barren rock. At the outer edges of the horizontal vein only the disseminated crystals are seen, grading from above and below to a central zone of more closely spaced crystals. Still farther out horizontally the replacement crystals decrease in quantity until only a band of shaly gouge remains along the bedding-plane fault. Such veins point to the similar development of some other symmetrical veins by the gradual growth by replacement from disseminated crystals along the favorable ore horizon. Much similar evidence of the formation of the veins by replacement and impregnation have been observed elsewhere in the district. Although most banded veins are fracture fillings, many of them are developed by replacement and impregnation.

Banded veins which fill fractures are most common in the competent beds of the Galena dolomite and the Ion member of Decorah formation and are somewhat less common in the Guttenberg member of the Decorah formation, and in the Quimbys Mill and McGregor members of the Platteville formation. Replacement veins are more common in the Guttenberg and Platteville than in the Galena and Ion. Ore in the Spechts Ferry shale member is almost always disseminated.

Monomineralic veins are particularly abundant in the gash-vein lead deposits, where galena is commonly the only mineral present. The veins are unbanded and consist of masses of large crystals extending across from one vein wall to the other. Many monomineralic veins are in relatively tight and narrow joints that strike northwest or northeast. In many east-trending joints galena is in two parallel bands of crystal or crystal clusters on the walls of the open fractures, and the well-formed crystals project toward the open vein center. The two bands branch in solution openings and line the walls of the cavity as crystal crusts, meeting again as a vein on the sides and continuing along the controlling joint. Such crystallized vein ore is known by the miners of the district as "cog lead", in contrast to the solid unbanded veins of "sheet lead" found in the northwest- and northeast-trending joints.

Veins in both pitches and flats have been broken by late movements along the fractures in many places. Many of these movements took place during the deposition of the later ore minerals. The earlier formed bands of sulfides have been fractured and brecciated, and then re-cemented by the later ore minerals such as marcasite, barite, and calcite. The original symmetrical banding is disturbed or destroyed in veins of this type. Commonly, veins of later minerals are deposited between the separated bands of the earlier minerals, and at first glance give the appearance of an unusual depositional sequence. Fracturing continued in other places until the original ore bands were crushed to small angular fragments. Shears and slickensides in the older ore fragments are evidence of these movements. In some places the earlier formed vein was opened along one wall by the renewed movement and later minerals were deposited in the newer fracture. Such asymmetric veins are commonly seen in the ore bodies, particularly along bedding-planes. The upper surface of bedding-plane veins more commonly part from the wall rock to form the newer fracture than the lower one, so that commonly such complex veins contain double bands of sphalerite in the older lower part, and calcite and a little marcasite in the upper part. Some of these veins consist of a regular sequence of pyrite, marcasite, and sphalerite on one wall, but perhaps only marcasite or calcite on the other wall. Various combinations of minerals form asymmetric banding of this type.

CAVITY FILLINGS IN FAULT BRECCIAS AND FRACTURED ZONES

This type of ore occurrence is in reality a variety of the vein type, and consists of veinlets cementing breccias. It includes true breccias away from and along main fractures and crackle breccias produced by fracturing the rock with little actual movement or rotation of the fragments (fig. 54).

The ore veins in the breccias are very similar to the larger veins but are veinlets. Symmetrical banding is common in the veinlets in the interstices between the angular rock fragments of the breccias. Commonly the rock fragments are armored with a pyrite film that also replaces the edges or all of the rock fragments. The central parts of the veinlets contain the ore minerals deposited in their regular order toward a calcite center or vug.

Considerable replacement of the rock fragments by the ore and gangue minerals has occurred in many of the breccias (fig. 54). The replacements include both the sulfides and such gangue minerals as quartz (jasperoid), calcite, and dolomite. The limestones and dolomites are either replaced by ore minerals, or crystals of sphalerite or galena have formed interstitially between the original rock grains with little actual replacement of the grains themselves. In shaly rocks impregnations of well-developed crystals of sphalerite or galena have pushed aside the grains of the rock in which they formed so that the shale curves around the sulfide crystals.

Renewed deformation during ore deposition caused movement in many places along many fractures. As a result, breccias cemented by the earlier zinc, lead, and iron sulfides have been recrushed and re-fractured. The later minerals of the paragenetic sequence, such as marcasite, barite, and calcite and, locally, even later sphalerite and galena have been deposited in these late fractures. Elsewhere, the later brecciation and fracturing took place in parts of the rock unaffected by earlier deformation, and so these later minerals alone are deposited in the fractures. Even less commonly, postore fractures and breccias are seen in which no deposition of any sort has occurred.

Slickensides are abundant on the rock and ore surfaces in both the earlier and the later formed breccias. In earlier formed breccias, unsheared ore is found against slickensides on the walls, indicating that the ore only filled in the grooves of the earlier formed glide planes. However, in later breccias the slickensides are found along the vein walls, cutting through the earlier ore and rock fragments indiscriminately.

Breccia ore is found in practically all the mineralized strata except the soft, plastic Spechts Ferry shale member. It is particularly characteristic of the ore bodies in the brittle Quimbys Mill member and, to a lesser extent, in the competent dolomitic beds of the Galena and upper part of the Decorah formations. Only locally are such ore breccias found in the Guttenberg member, as these shaly strata more commonly flowed plastically and thus tightly sealed in the existing fractures.

CAVITY FILLINGS IN SOLUTION BRECCIAS

One of the more unusual, distinctive types of ore occurrence in the district is in cavities of solution breccias. These solution breccias are essentially restricted to the dolomitic Stewartville and Prosser members of the Galena dolomite and to the similarly dolomitic Prairie du Chien group, but are not uncommon in the dolomitic Ion member of the Decorah formation. Everywhere the solution breccias are associated with massive, thick-bedded dolomites or limestones in which dolomitization has occurred. The dolomitization in both rocks, though fairly complete, has been somewhat selective and dolomite occurs as irregular, somewhat-rounded masses and blobs in the replaced rock. This irregular replacement can be seen everywhere in outcrops of dolomitic rock, particularly in the zone of weathering where the patchy nature of the dolomitization has permitted ground waters and other weathering agencies to leave characteristic pitted, porous masses of dolomite.

A network of feeding fractures and, in many places, a brecciation of the beds by deformation are generally associated in the ore bodies. Some of the rock has become so porous that it appears to have collapsed under the weight of the overlying beds, forming tumbled solution breccias. However, the brecciation in most places was apparently earlier than solution; the fractures acting as feeders for the dissolving solutions. Many solution cavities have been filled, or partly filled, with the minerals deposited by the ore-bearing solutions, forming a type of ore deposit known locally as "brangle." Some rock replacements in the cavity walls accompanied the deposition of ore.

Solution breccias are particularly abundant in the dolomitic beds of the central slightly fractured "core ground" area between the two opposing reverse fault zones of the pitch-and-flat ore bodies. They are also typical of ore deposited in the openings of the lead-bearing joints.

The first mineral deposited in a large number of these deposits was dolomite in small well-formed rhombohedral crystals that line the solution cavities. Silica in the form of chalcedony and drusy quartz was deposited before dolomite in the cavities in a few deposits. This silica deposit is commonly accompanied by a partial to nearly complete chert replacement of the wall rocks. The first sulfide deposited was the usual film of pyrite that lines the cavities. The remainder of the minerals deposited in the cavities are in their regular order. However, banding of these later minerals is not as common as in the veins. Only one or two of the minerals are in a single cavity in most places. Sphalerite and marcasite are commonly found in one cavity, galena in a second, and perhaps late pyrite and calcite in a third. This selectivity diminishes where the cavities are closely spaced and interconnected by solution tubes, and the normal banding is more common. By piecing together the mineral relationships observed in several of these cavities, the writers found that the paragenetic sequence is the same as that observed in the other types of ore deposits.

DISSEMINATIONS BY REPLACEMENT AND IMPREGNATION DEPOSITS IN FAVORABLE BEDS

Replacements and impregnation deposits are associated with fractures, but the actual mineralization took place in the wall rocks rather than in the fractures. They are important types of ore occurrence, forming large commercial deposits; however, they are not as common as the more typical pitch-and-flat vein deposits or the gash-vein joint deposits and their associated solution breccias.

The disseminated deposits are most common in the more shaly strata. They are practically the only type observed in the Spechts Ferry shale member of the Decorah formation and are particularly abundant in the Guttenberg member immediately above. They have also been noted in the overlying Ion member as well as in all of the Platteville formation beneath. The local pyritic mineralization of the basal shale beds of the Maquoketa and a few of the known occurrences of mineralization in the St. Peter sandstone (Chamberlin, 1882, p. 510–511) are of this type.

All gradations between true vein-type ore bodies and true disseminated type occur, and ordinarily a single ore body may grade from one into the other, depending on the fracture development and the local conditions of the host rocks. Certain parts of the district are characterized by disseminated type ore bodies—for example, many of the known pitch-and-flat ore bodies in the vicinity of Potosi, Wis. Likewise, farther to the east, the deposits west of Platteville also consist entirely of disseminated ores, which change eastward to vein deposits. The deposits near Montfort, Wis. are all disseminated, whereas those to the north near Highland, Wis. contain both veins and disseminated ores. Disseminated deposits are less common in the southern parts of the district where fracture systems are better developed. Where present, most of them are small, or are small parts of large pitch-and-flat vein deposits.

The disseminated deposits consist of four subtypes:

1. Individual well-formed crystals replacing rock.
2. Individual well-formed crystals and groups of crystals impregnating rock.
3. Crystals formed interstitially with poikilitic texture without notable replacement of the rock grains.
4. Replacements of fossils.

The first two subtypes are most abundant, occurring in all the affected beds; the third is less common; and the fourth uncommon.

Replacement subtype.—True replacement crystals are more common in the dolomitic and calcareous beds. Euhedral crystals of the sulfides and associated minerals replace the calcareous and dolomitic beds at favorable horizons. The replacement commonly is somewhat spotty but tends to be concentrated in more favorable strata as horizontal layers of disseminated crystals. The Gray ore body in the NW¼ sec. 10, T. 27 N., R. 1 E. (Illinois), is of this subtype, combined with solution and true breccias described previously. Most of the principal controlling fractures, however, which are here unmineralized, are typical reverse faults and bedding-plane faults. In this ore body a large part of the replacement was in the dolomitic beds of the Decorah and Galena formations.

Replacements by the minerals accompanying the sulfides, such as dolomite, calcite, quartz, and barite, are common and widespread throughout the district.

Most of these replacements have been previously discussed in the section on alteration.

Within the ore bodies, in the surrounding areas, and in slightly mineralized rock away from ore bodies, calcite abundantly replaces the wall rocks as small to large crystals that retain some of the original textures of the rocks replaced.

Likewise, where barite is deposited, commonly the wall rocks of the veins have been considerably replaced by bladed, euhedral crystals of barite.

Impregnation subtype.—Impregnation crystals are almost restricted to shaly beds. Impregnations of the sulfides in the form of well-formed crystals and clusters compose ore bodies of mineable size in shaly rocks. Instead of replacing the shaly rocks, crystal growth has forced the adjacent beds apart. Rounded groups of sphalerite crystals formed in this manner are known locally as "strawberries" or "strawberry jack." The impregnations of crystals occur as bands lying horizontally along selected shaly beds. These ore deposits, like the others, appear to be controlled by reverse and bedding-plane faults, which are commonly unmineralized but relatively tight fractures cutting the deposits.

For the most part, impregnation subtype ore bodies are notably lean in iron sulfides. The zinc sulfide content may be two or three times as much as the iron sulfide content in such ore bodies. Galena is deposited alone in a few impregnation ore bodies, but more commonly it is a minor constituent associated with zinc and iron sulfides. Calcite and barite comprise very small proportions of these deposits because of the lack of free openings; however, the wall rocks are dolomitized and silicified as in other deposits. Dolomitized rock is restricted mainly to calcareous beds.

Where the few cavities in these deposits allowed free crystallization, and two or more minerals are in contact, the usual paragenetic sequence of ore deposition is seen.

Interstitial crystal subtype.—The occurrence of crystals of the vein and gangue minerals formed interstitially without notable replacement of the rock grains is much more restricted. Galena, sphalerite, pyrite and marcasite, and calcite are all found in this subtype of deposit. Crystals of these minerals fill the spaces between the rock grains and replace a few of them. Crystals formed in this manner commonly have large cleavage surfaces that pass uninterruptedly between and around the included rock grains, indicating that they are large single crystals and not aggregates of small ones. This subtype never forms large ore bodies but is seen locally within the ore deposits of all other types. Galena, sphalerite, barite, and pyrite occur less commonly than calcite in crystals of this type.

Replacement of fossils subtype.—One of the most unusual features of the deposits is the local selective replacement of fossils by the ores and associated minerals. The replacement is complete in most examples; the fossil retains its original form and organic textures. This subtype, which is of no commercial importance, is most commonly found in the fossiliferous, calcareous beds of the Decorah and Platteville formations but is also found in the overlying Galena dolomite.

The first indication of silicification of the rocks by ore solutions is the selective replacement of fossils by cryptocrystalline silica. Such replacements are on the fringes of silicified areas where no other apparent silicification is observable.

ORE-BODY RELATIONS IN THE CAMBRIAN, LOWER AND UPPER ORDOVICIAN, AND SILURIAN ROCKS

Deposits of sulfides have been found in all the geologic formations in the district. However, all known lead, zinc, and copper deposits of commercial, or possible commercial size are in the Prairie du Chien group and the Platteville, Decorah, and Galena formations, particularly the last three, and only these four rock units are known to show promise of future discovery of commercial deposits.

No deposits of the pitch-and-flat type are known in the rocks above or below the Platteville, Decorah, and Galena formations. In these older and younger rocks, the known deposits are fissure veins or lodes along faults, mineralized breccia zones, replacements or impregnations, and a few gash-veins in bedding planes or joints.

MINERAL DEPOSITS IN THE CAMBRIAN ROCKS

Strata of Late Cambrian age are exposed in the extreme northern part of the district (Strong, 1882, p. 3–98), in the valley of the Wisconsin River and its tributaries. These beds locally contain deposits of hematite, galena, and chalcopyrite and their associated oxidation products. These deposits are of commercial or marginal grade in only a few places. (See fig. 101.)

Moses Strong (1882, p. 49–56) described twenty-two localities in which notable deposits of hematite and limonite occur in the sandstones of Cambrian age. In several of these localities he noted that the hematite and limonite were oxidation products of primary iron sulfides. As most of these deposits are very similar, probably most of them are vein or breccia deposits formed from the oxidation of pyrite and marcasite. The most important of the hematite deposits is at Ironton, Sauk County, Wis., in the SW¼ sec. 10, T. 12 N., R. 3 E. Iron ore was mined here for more than twenty years. This deposit was described by both Strong (1882, p.

54) and Chamberlin (1882, p. 518–520). Chamberlin describes some of the structures of the deposit:

The exposed portion of the deposit lies from one to two hundred feet below the upper face of the Potsdam "[Upper Cambrian]" sandstone. It is situated within a belt of rock from ten to thirty rods in width having a northeasterly-southwesterly strike, which is indurated to such an extent as to be readily distinguishable from the adjacent friable sandstone * * * It has been so far compacted that its original regular cleavage into slabs has been largely replaced by an irregular fracture * * * Along the line of this belt are a few springs of really magnificent proportions. The ore, as developed within the mine, is intimately intermixed with large angular blocks of indurated sandstone * * * The only rational conception of its formation. . . . is that the ore accumulated by aqueous deposition among the fractured blocks, while they still occupied a subterranean position within the indurated belt, which I conceive to be a line of local breakage, analogous to the fissures of the lead region * * * During its accumulation, slight movements of the formation are supposed to have caused fractured blocks to fall from above into the accumulating deposit, so that certain of them are completely enveloped within the ore.

Chamberlin mentioned a similar deposit on Hagerman Hill, a mile and a half southeast of LaValle, Wis., in sec. 34, T. 13 N., R. 3 E. Here an ore like that at Ironton is associated with indurated and brecciated rock, and also is impregnated with malachite and chalcopyrite.

A small bedding-plane vein of chalcopyrite mixed with some pyrite, about an inch thick, was discovered in the sandstone of Cambrian age in the bank of the Wisconsin River in the SE¼ sec. 35, T. 9 N., R. 1 E. by Moses Strong (1882, p. 56).

Lead has been found in quantities of several thousand pounds in the uppermost sandstone of Cambrian age (Madison sandstone member) at the Lansing lead mine, near Lansing, Allamakee County, Iowa in the NW¼ E½ sec. 10, T. 99 N., R. 4 W. This deposit, at the north end of the mine, is a vein along a vertical fault that contains lead ore in the Oneota dolomite of the Prairie du Chien group, above (Calvin, 1894, p. 106–107, Leonard, 1896, p. 56).

Galena was mined from the Dresbach sandstone, Dresbach, Minn., in a fault which is 4 feet wide at the surface, but more narrow below. The fault has a considerable throw according to Winchell (1884, p. 258). The deposit contains galena and pyrite, which are disseminated in the sandstone on both sides of the fissure. Some ore in the fault cements a rock breccia. Galena and cerussite are in veinlets in limestone of the Prairie du Chien group above the mine. The mine opening is about 200 to 250 feet below the top of the Cambrian.

A disseminated sulfide deposit of pyrite and marcasite and a little sphalerite are deposited in the Franconia sandstone on the Leix property at Montfort, Wis. (Heyl, Lyons, Agnew, 1951). The sulfides are in shaly glauconitic sandstone beds as intergranular cements of quartz grains.

MINERAL DEPOSITS IN THE PRAIRIE DU CHIEN GROUP

Much of the Prairie du Chien group is dolomite in many respects similar to the Galena dolomite, and apparently is a favorable host rock for ore. Galena has been found in it at a number of places and, in aggregate, not an inconsiderable quantity of lead has been mined. Zinc and copper deposits are known in several localities in the Prairie du Chien group. Almost all the known occurrences are north of the main district (fig. 101), where this group has been exposed by erosion.

Although deposits of ore minerals in the Prairie du Chien group are numerous, few have proven to be of economic worth. They have been described in some detail in former reports (Calvin, 1894, p. 105–107, Percival, 1855, p. 66, Chamberlin, 1882, p. 511–517, Strong, 1882, 49–56).

Recent deep drilling (1949–1950) in the Prairie du Chien group by the U. S. Geological Survey (Heyl, Lyons, Agnew, 1951, 35 p.) has disclosed the occurrence of sphalerite, pyrite, and marcasite at several localities in the central part of the district. The most notable quantities of sphalerite were found at the Crow Branch Diggings (fig. 21) in dolomite beds that underlie an ore body in the Decorah and Platteville formation. The sulfides, dolomite, and jasperoid fill fractures and replace dolomite in brecciated rock.

Probably the most productive of the deposits in the Prairie du Chien group was the Lansing lead mine. It is also one of the most interesting geologically, as the ore is deposited in both the Oneota dolomite of the Prairie du Chien group (Ordovician) and also in the uppermost part of the Madison sandstone member (Cambrian). This mine has been described by Calvin (1894, p. 105–107), Leonard (1896, p. 53–56), and Jenny (1894, p. 211–212, 644). The ore is in a north-trending fault in which galena was in commercial quantities for a distance of 1,200 feet. The fault has been traced to a depth of at least seventy-five feet and possibly over a hundred feet. The lead ore forms a vertical vein 3 to 4 inches thick, and consists of galena at depth and mostly cerussite at the surface. The vein is bordered by bands of ferruginous clay, accompanied by chert nodules. The clay is a weathering product of the wall rock and probably of original iron sulfides. The vein continues to a depth of 25 to 30 feet and then changes to scattered disseminated crystals that fill the fault to a few feet above the Madison sandstone member. The galena is silver bearing (Leonard, 1896, p. 53–56).

Galena occurring as small crystals in veinlets in brecciated Oneota dolomite was formerly mined on a branch of Mineral Creek, 6 miles northwest of Waukon, Allamakee County, Iowa (Leonard, 1896, p. 56–57). The ore is localized along small irregular shattered areas in the upper beds of the Oneota, just below the New Richmond sandstone. No regular fracture system is apparent, just irregular breccia zones. The galena occurs in octahedral crystals about half-an-inch in diameter, scattered within small veinlets of calcite containing some marcasite. Fine-grained reniform sphalerite is more abundant than galena, and is deposited as small nodules in the veins near the surface. It is replaced by smithsonite. The gangue minerals calcite, chalcedony, jasperoid, and drusy quartz abundantly replace the brecciated dolomite.

According to the old descriptions, most of the other lead deposits in the Prairie du Chien are very similar in geology to those on Mineral Creek except that sphalerite is uncommon. The lead deposits west of Highland, Wis., in sections 31, 32, T. 7 N., R. 1 E. (pl. 1), are among the few in the Prairie du Chien group in Wisconsin where ore was in commercial quantities. Considerable attention has been paid them by geologists who were interested in the ore-bearing potentialities of this group, and they arrived at conflicting conclusions. The first geologist to describe the Highland deposits was Percival (1855, p. 66, 1856, p. 59, 63), who was enthusiastic; he was followed by Whitney (1862, p. 408–413), who took a very pessimistic view of them; Chamberlin (1882, p. 511–517) and later Ellis (written communication, 1904) were much more favorable in their opinions of them.

The main ore-bearing strata apparently are the lower part of the Shakopee dolomite of the Prairie du Chien group, and most of the pits are in these strata about 30 to 40 feet below the St. Peter sandstone. A quarry, opened at the level of the main mineralized beds in the NE corner NW¼NW¼ sec. 32, T. 7 N., R. 1 E., presents a good exposure of the type of mineral deposit, beds, and structure involved. Small to large crystals of galena are disseminated in jasperoid in the southeast corner of the quarry. Here the main area of mineralized rock is localized in a brecciated, silicified cryptozoan bed as an irregular lens about 2 or 3 feet thick, and traceable about 30 to 40 feet laterally along the quarry walls to the west and north. The main controlling fractures apparently are bedding-plane faults along a small 6-inch-thick apple-green glauconitic (or celadonitic?) lens of shale at the base of the 10-foot-thick, massive cryptozoan bed. Considerable brecciation and thrusting have also occurred in the cryptozoan bed. The gray dolomite is replaced by light-gray jasperoid and drusy quartz, and also by fine-grained, pink dolomite in bands and veins that cut across the beds. The galena is in isolated crystals deposited in cavities of the silicified rock in small mineable quantities.[31] In the most mineralized rock considerable solution of the original dolomite beds took place. Indistinct, vertical fractures cross northward through the mineralized zone. The silica was deposited before the pink dolomite and the galena after it. Bright green stains of redeposited glauconite are common. Similar areas have been noted in the Prairie du Chien elsewhere in the district, such as the quarry in the SW¼ sec. 20, T. 6 N., R. 5 W. where sphalerite is deposited with the other minerals.

MINERAL DEPOSITS IN THE ST. PETER SANDSTONE

The St. Peter sandstone is one of the most barren of all the formations of the district. The only deposits are disseminated pyrite, marcasite, and very small quantities of galena, sphalerite, and chalcopyrite.

In a few places in the district galena and sphalerite have been found in the uppermost parts of the St. Peter. Reported occurrences are at Mineral Point, Wis. and at the Crow Branch diggings, two miles southwest of Livingston, Wis. Percival (1855, p. 55) was informed by J. Bracken that a fracture containing zinc and iron was traced into the St. Peter sandstone at Mineral Point, Wis. The occurrence at the Crow Branch diggings was mentioned by Whitney (1862, p. 363).

Drilling in the district in 1945–1949 (Kelly, 1949; Heyl, Lyons, Agnew, 1951) has disclosed that the upper part of the St. Peter sandstone directly underlying zinc deposits in the Decorah and Platteville formations is commonly heavily impregnated with pyrite, marcasite, and small amounts of sphalerite and galena. Also, in places the sandstone is heavily impregnated with hematite and limonite, probably derived from pyrite originally deposited as intergranular cement of the sand grains. Large areas of St. Peter sandstone containing abundant hematite are in structurally disturbed areas at Red Rock, Wis. and between Argyle and Hollandale, Wis. Percival (1856, p. 62–63) described a similar pyritized area, in which some original pyrite remains, on Skinners Branch in secs. 3 and 4, T. 1 N., R. 6 E.

MINERAL DEPOSITS IN THE MAQUOKETA SHALE

Isolated crystals, nodules and small veins of the ore and gangue minerals of the district have been found in a few places in the Maquoketa shale near Scales Mound, Ill., Galena, Ill., and Eleroy, Ill., and near Dubuque, Iowa. Sphalerite has been noted also at the Glanville prospect near Scales Mound, Ill. (NE¼NW¼ sec. 24, T. 29 N., R. 2 E.) (pl. 1). Here in about the middle of the Maquoketa are thin bands

[31] In November 1946, three or four tons of lead concentrate were shipped from this quarry, according to C. W. Stoops, ore buyer. Written communication to A. V. Heyl, 1948.

of dolomite in which some sphalerite and barite are deposited. The sphalerite occurs with barite in small cavities as druses in both the weathered and unweathered rock. The individual masses are one-half to three-fourths of an inch in diameter.

A second, more unusual, prospect is that on the Willard Stadermann farm (SW¼NE¼ sec. 14, T. 27 N., R. 6 E.) at Eleroy, Ill. (pl. 1). According to Hershey (1899, p. 240–244) most of the rock was mineralized with pyrite, galena, sphalerite, native copper, barite, chalcopyrite, and a few nodules of pinkish, gold-bearing quartz. The galena, sphalerite, and barite are reported to occur in small veins and lenses very near the base of the Maquoketa shale. The highly fossiliferous layers in the depauperate zone at the base of the Maquoketa are almost completely pyritized.

Willard Stadermann (oral communication to A. V. Heyl, 1943) said that gold-bearing quartz was found with ankerite nodules in a one-foot layer of massive dolomite that was just above a 6-foot-thick carbonaceous shale bed near the base of the Maquoketa shale. He said that the gold was in small isolated nodules of a pale pink quartz, which apparently filled cavities with crystallized ankerite within this dolomite layer. Specimens sent in assayed about 4 troy ounces of gold to the ton according to Stadermann, and his statement checks with assays given in the Hershey report (1899, p. 240–244).

MINERAL DEPOSITS IN THE DOLOMITE OF SILURIAN AGE

Galena, pyrite, and traces of sphalerite have been found in the dolomite of Silurian age at a few places in and near the district (fig. 101), although always in small quantities. Specimens of galena have been found at Sherrill Mound, north of Dubuque, Iowa and unsuccessful attempts have been made to develop such deposits near Clinton and Anamosa, Iowa (Bain, 1906, p. 66; Calvin, 1895, p. 110). Calvin states that small quantities of galena are of widespread occurrence in the Silurian units of Jones County, Iowa. About 6,000 pounds of lead ore was mined about 1890 in sec. 13, and about 5,000 pounds of lead ore in sec. 19, T. 84 N., R. 4 W.

RELATIONS BETWEEN ORE DEPOSITION AND LARGER GEOLOGIC FEATURES

Plate 1 shows the location of the larger zinc, lead, and copper mines and most of the old lead and copper mining areas. This map, however, does not show the outermost fringe deposits of the district. Most of the fringe deposits are lead, copper, and iron (hematite and limonite) ore bodies worked many years ago (fig. 101). Although nearly all of these are small, at least one lead mine and one hematite mine were successful producing properties of considerable size. Small quantities of zinc have been found in the fringe areas, but never in economic quantities. The total mineralized district, including all of these outlying deposits, is about 10,000 square miles; however, the presently active part of the district (1950) includes only about 650 square miles in the central part.

The relations between ore deposition and the larger geologic features are summarized below. A more detailed discussion has been published (Heyl, Lyons, Agnew, Behre, 1955).

GEOLOGIC RELATIONS OF THE DISTRICT BOUNDARIES

The main district is bounded on the south and southwest by a deeply incised cuesta (pl. 1) (Grant and Burchard, 1907; Shaw and Trowbridge, 1916). The cuesta consists of Maquoketa shale, and dolomite of Silurian age, which units cover the Galena, Decorah, and Platteville formations that are most favorable for lead and zinc deposits. Several mineralized areas are exposed by erosion through these capping rocks in the deeper valleys south and west of the northward-facing cuesta. Notable examples are the lead deposits in the Apple River valley near Elizabeth, Apple River, and Warren, Ill., but other areas are shown in Illinois and Iowa (pl. 1). The actual boundaries of the district probably extend for many miles to the southwest and south of the edge of the covered area as is shown by: (1) the outlying mineralized areas in erosional windows; (2) the large number of intensely mineralized areas along the edge of the main cuesta face as at Scales Mound and Galena, Ill., and from Dubuque to Rickardsville, Iowa; (3) the small deposits of lead in the rocks of Silurian age far to the southwest in Iowa (fig. 101) near Lytle Creek, Jackson County, and south of Dyersville, Dubuque County, and still farther near Clinton (Bain, 1906, p. 66) and Anamosa (Calvin, 1895, p. 110); (4) the known deposits extending beneath the cap rocks as Bautsch mine (pl. 1) south of Galena, Ill., and (5) the ore bodies of the New Blackstone and Calumet mines south of Shullsburg, Wis., which lie beneath a thick Maquoketa shale cover.

The known district boundary to the southeast in Illinois is determined by two factors: (1) large areas of Maquoketa shale and dolomite of Silurian age that conceal the favorable host rocks; and (2) the overlapping glacial drift that marks the east edge of the Driftless Area. Quite possibly the ore-bearing area may extend for many miles to the southeast beyond the present edge of the main district at Apple River and Warren, Ill., but the deposits probably decrease gradually in size and abundance as the true limit of the mineralized area is approached. In this southeastern area a number of nearly forgotten deposits are exposed in erosional windows in the deeper valleys where either the capping rocks have been eroded away west of the drift boundary, or where both the capping rocks and the glacial drift have been removed within the drift-covered area. The main localities are near Morseville, Stockton, Eleroy, Freeport, and Oneco, (pl. 1) and farther south to Mount Carroll, Ill. (See fig. 101.)

In Wisconsin the district boundary on the east is also determined by two factors: (1) the overlap of the glacial drift marking the east edge of the Driftless Area, and (2) the erosion of the most favorable beds (progressively the Galena, Decorah and Platteville formations) along the stream valleys, and farther east, where the strata rise toward the Wisconsin arch. Here all of the favorable formations have been removed except in a few erosion outliers in the least-dissected interstream areas. Possibly the progressive decrease towards the east in the close spacing, number, and size of the ore deposits in some of the remaining outliers of favorable beds suggests that the true east boundary of the lead deposits may not be far east of the east margin of the Driftless Area. The widely spaced deposits south of Mount Horeb, northeast of Monticello and east and south of Monroe, Wis., may represent the true east edge of the district. On the other hand, the original district edge may be quite a few miles farther east, as suggested by small quantities of sulfides found near Brodhead, Wis., and on the east side of the Wisconsin arch near Appleton, Milwaukee, Cambria, and Rio, Wis.

The north boundary of the main district lies between the Wisconsin River and Military Ridge, the crest of which is marked by the Chicago and Northwestern Railroad between Madison and Fennimore, Wis. (pl. 1). Along this boundary beds of Platteville, Decorah, and Galena form a northward-facing cuesta (Grant and Burchard, 1907), north of which they have been eroded away. Probably the edge of the main district between Blue Mounds and Highland, Wis., formerly extended many miles north of its present position because for a distance of about 30 miles to the north, widely scattered lead, copper and iron (oxidized iron sulfides) deposits occur in the underlying Lower Ordovician and Cambrian formations. Similar deposits extend far to the northwest at Mount Stirling, Wis., Lansing and Waukon, Iowa, and Dresbach, Minn., to form a part of the widespread fringe deposits of the district.

Within the main district south of Military Ridge the St. Peter sandstone and Prairie du Chien group outcrop widely along the larger streams. The principal outcrop areas of these rocks have been mapped by Grant and Burchard (1907) and lie west and south of Mineral Point and near Hollandale, Iowa County, Wis. Only a very few ore deposits are known in these outcrop areas of the older formations.

From Fennimore, Grant County, Wis., the north boundary of the main district turns toward the southwest through Bloomington, to Glen Haven, Wis., and then across the Mississippi River into Iowa to the area northwest of Guttenberg, Clayton County. Here is located the Guttenberg group of lead mines. From this point the short west district boundary extends south from the Guttenberg mines to the Turkey River west of Millville, Iowa, and thence southeast to the cuesta formed by dolomites of Silurian age to join the previously described southwest boundary. This western part of the north boundary of the main district and the short west boundary appear to be true boundaries beyond which practically no ore was deposited in the favorable beds of the Platteville, Decorah, and Galena.

Characteristic of this probably true boundary areas are widely spaced, small lead deposits. Zinc has not been reported from most of these deposits. Only one large center of intense mineralization, the Beetown area, lies near this district margin and even this area is from 6 to 10 miles from the next nearest centers of abundant deposits near Cassville and Potosi, Wis. Futhermore a decrease in the intensity of the mineralization is suggested by the deposits in the Guttenberg area. Here the mineralogy of the ores is very simple, consisting of thin coatings of pyrite and marcasite on the wall rocks, scattered small galena crystals perched at intervals on the iron sulfide coatings, and a little barite. The remainder of the space in the abundant fractures and cavities in the ore bodies is filled with calcite so that it is the most abundant mineral of the deposits. Probably the minerals were deposited from weak solutions far from their source, as might be expected of deposits on the margins of a district.

DISTRIBUTION OF THE ORE DEPOSITS

Within the district are many areas of closely spaced mines, between which the intervening country contains only a few known deposits or none (pl. 1). The largest of these mining areas consists of about 280 square miles of roughly triangular shape with Platteville, Wis., as its northern point, Shullsburg, Wis., as its eastern corner, and Galena, Ill., as its southern point. Within this triangular area the most abundant mines are between Hazel Green and Shullsburg, Wis., and near Platteville, Wis. Most of the zinc production of the district and a considerable part of the lead production came from this principal area. To the northeast of the principal area is a second large mining area of about 215 square miles extending from the southwest corner of Iowa County, Wis., north to Livingston, Wis., and east to Mineral Point, Wis. To the northeast this northern area extends through Dodgeville, Wis., to Ridgeway, Wis. The most important mining centers are Mifflin (mainly zinc), Linden (lead and zinc), Mineral Point (lead, zinc, and copper), and Dodgeville (lead and zinc). Most of the rest of the zinc production of the district came from this northern main area, which also was a major source of lead. Some copper was produced near Mineral Point, Linden, and Gratiot, Wis.

The boundaries of the two large mining areas are defined chiefly by a decrease in the quantity of ore deposited, but also by erosion of the favorable beds, by lack of prospecting, or by beds of Maquoketa shale and dolomite of Silurian age which cap the principal host rocks. For example, erosion of the favorable beds cuts off the northern mining area to the northeast of Dodgeville, Wis., (pl. 1) and to the south of Mineral Point, Wis., and lack of prospecting for either lead or zinc in the nearly flat land between Livingston and Montfort, Wis., has probably prevented the discovery of ore deposits connecting the main northern area to the smaller Montfort group of mines.

Some of the smaller mining areas such as the Guttenberg, Beetown and Sinsinawa areas are probably natural centers of mineralization surrounded by adjacent barren land or very sparse deposits. The Elizabeth, Ill., group of mines and those near Warren and Morseville, Ill., are probably parts of larger mineralized areas exposed in erosional windows in the capping rocks. A few mining areas are situated in erosion outliers of the most favorable strata, such as the Highland, Wis., group and the Sugar River mines northeast of Monticello, Green County, Wis. Previous to the progressive erosion of the Galena, Decorah and Platteville formations, these mineralized areas may have been connected by deposits to those adjacent.

The underlying rocks of the Prairie du Chien have been exposed by erosion in the deeper valleys in the western part of the Highland group of mines (pl. 1). Here the dolomites of the Prairie du Chien are mineralized with lead and iron sulfides (mine 309) to form what may be a mineralized "root" beneath the richer deposits in the Platteville, Decorah, and Galena formations. The Demby-Weist mine group (mine 290) may represent a similar "root" area in the Prairie du Chien group and Trempealeau formation from which a former overlying mineralized center has now been nearly completely eroded except for one small lead deposit in the Decorah formation west of the main group of mines.

ORE DEPOSITS AND THE LARGER FOLDS

The locations of the ore deposits appear to be controlled in a general way by the larger folds of the district (pl. 8), particularly in the northern one-half. The most heavily mineralized areas of the district are within and follow the larger synclines at least in part. For example, the Crow Branch mine (pl. 1, no. 213), southwest of Livingston, Wis., is adjacent to the axis of a large syncline which trends east northeast for 20 miles past the south edge of Dodgeville, Wis. Associated with the axis of this syncline toward the east from the Crow Branch mine are the Coker mines (nos. 225, 226, 227), the Linden group, and the Dodgeville group, all heavily mineralized areas. Similarly, a large syncline extends from Potosi, Wis., eastward through Platteville and Calamine, Wis. (pls. 1, 8). Along this fold are the mining centers of Potosi, Tennyson, Platteville, and Calamine. Large and important deposits seldom are situated near the crests of the large anticlines. This relationship is particularly apparent between Beetown and Lancaster, Wis., and also is discernable in anticlinal areas in many other parts of the district.

In the southern part of the district most of the principal mining areas lie on the gentle south limb of the large anticline extending east from Sherrill, Iowa, through Jamestown and Cuba City, Wis. On this south limb from west to east are (1) the mines near Dubuque, Iowa, (2) those near Sinsinawa, Wis., and (3) the most concentrated mining center of all, that between Hazel Green and Shullsburg, Wis., (Heyl, Agnew, Behre, Lyons, 1948). This last area lies south of and is partly enclosed by a marked northward bow of the axis of the large anticline. An extension of the Hazel Green-Shullsburg mining area to the southwest into Iowa along the Tete du Mort River follows, in part, a southwest-trending syncline which extends through Galena, Ill. (Willman and Reynolds, 1947).

ARRANGEMENT OF THE ORE-BEARING JOINTS

Practically all of the older reports contain maps showing the location and arrangement of the galena-bearing joints throughout the district, and the Potosi, Beetown, and Pikes Peak-Center Grove maps (pls. 4, 6, 7) show the arrangement and pattern of these mineralized joints.

The mineralized joints are concentrated in apparently localized areas although similar, unmineralized joints and openings are equally abundant throughout the entire district.

However, attempts to show a definite pattern of these fractures regionally have been without much success

(Percival, 1855, 1856; Murrish, 1871, p. 9–11; Chamberlin, 1882, p. 441–446).

At least some lead-bearing areas are apparently directly related to the larger folds, and in a few places to the underlying zinc-deposits. The centers of lead mineralization, like those of zinc mineralization, tend to occur in and along the major synclines.

The areas of most abundant lead deposits are located in reference to the main towns within or adjacent to them (pl. 1). They are:

1. Hazel Green-Shullsburg, Wisconsin area
2. The Galena, Illinois area
3. The Dubuque, Iowa area
4. The Potosi, Wisconsin area
5. Elizabeth, Illinois area
6. The Platteville, Wisconsin area
7. The Beetown, Wisconsin area
8. The Linden, Mineral Point, Dodgeville, Wisconsin area.
9. North Buena Vista-Turkey River, Iowa area
10. Montfort, Wisconsin area
11. Calamine-Darlington, Wisconsin area
12. Apple River-Warren, Illinois area
13. Blue Mounds, Wisconsin area
14. Guttenberg, Iowa area
15. Waldwick-Blanchardville, Wisconsin area
16. Wiota, Wisconsin area
17. New Glarus-Sugar River, Wisconsin area
18. Highland, Wisconsin area

Within these areas, the localization of the lead-bearing joints is discernable in some places. Some joints directly overlie and follow the axes of second-order folds. However, in many places, the major mineralized joints strike diagonally across such folds, and die out near the edges of the folds in an echelon pattern.

Good examples of echelon patterns can be seen in many parts of the district. For example, an echelon series of N. 77° W. trending lead-bearing joints are restricted along the intermediate syncline that begins with the Vinegar Hill mine in sec. 21, T. 29 N., R. 1 E., Illinois and passes northeasterly to Buncombe, Wis. (pls. 1, 8). Furthermore, this echelon group of lead-bearing joints continues on the same trend to the southwest beyond the point where the syncline has as yet been traced. Similarly, the syncline containing the Crawford and Martin mines, which, however, trends northeast, is marked by a similar echelon group of mineralized joints, that closely follow the trend of the fold (pl. 5). However, the strikes of the east-striking joints related to this fold are less constant, and northeast-striking joints are also common. Similar patterns not as definitely associated with folds are present elsewhere in the district.

In linear pitch-and-flat ore bodies of both the northwest and east trends, the relation of the lead-bearing joints to both the associated folds and underlying zinc ore bodies is more clear. In these places, the lead-bearing joints immediately overlie the synclines that contain the zinc deposits and in places are concentrated directly over the zinc ore bodies. Where present, these lead-bearing joints strike nearly parallel to the synclines in which they lie, and in some places the fractures are not joints, but instead the top parts of the reverse faults that control the zinc ore bodies beneath. These faults have steepened to nearly vertical fractures which closely resemble the lead-bearing joints. However, the areas of fractures parallel to and overlying the linear ore bodies are very local and by no means outline the structures.

ORE DEPOSITION AND FRACTURES

Only ore deposits along major faults will be discussed, inasmuch as the relations of the smaller fractures to ore deposition have been previously described. An area of secondary dolomitization 100–500 feet wide follows both the Mifflin fault (pl. 2), and the Capitola (pl. 8) fault west of Platteville, Wis., as far as they have been traced. Sphalerite, galena, and the iron sulfides have been deposited locally in subsidiary fractures along both of these faults. Along the Mifflin fault these sulfides were mined in the Old Slack mine, and along the Capitola fault they were mined in the Capitola mine (pls. 1, 8). The major faults themselves apparently were mineralized only with iron sulfides. However, the Crow Branch mine (pl. 1, mine 213) lies along a 100–300 foot wide reverse and bedding-plane fault zone. This fault zone lies along the northerly flank of the Mineral Point anticline and apparently represents the eastern end of the major reverse fault which extends westward along the northerly anticlinal flank. At the Crow Branch diggings, and for about a mile to the west, this fault zone is heavily mineralized with galena, sphalerite, barite, and the iron sulfides. Secondary dolomite accompanies the sulfides.

ZONATION OF ORE DEPOSITS IN THE UPPER MISSISSIPPI VALLEY DISTRICT

The Upper Mississippi Valley zinc-lead district shows zoning of four different types, namely, (1) regional horizontal zoning of several of the primary ore minerals, (2) local horizontal zoning within centers that are more intensely mineralized, (3) vertical zoning of the ore minerals in relation to the entire mineralized stratigraphic sequence, and (4) vertical and horizontal zoning within individual ore deposits. All four types of zoning are superimposed upon each other, and causing the pattern to be complex.

REGIONAL HORIZONTAL ZONING

The only study of the regional horizontal zoning of the district, by W. H. Emmons (Emmons, 1929, p. 221–271, especially p. 256–271) is based upon the data recorded by earlier investigators. Emmons postulated an elongate central "copper-gold-zinc-lead" zone 10 to 15 miles wide that trends N. 42° W. across the entire district. Galena and sphalerite are accompanied by chalcopyrite within this zone, and gold is found in two places. Around this central zone are areas of lead and zinc deposits that change into lead alone at the edges of the district.

Studies by the writers have corroborated Emmons' regional zonation picture but recognized additional complexities. A somewhat irregular copper zone, 6 to 25 miles wide and at least 250 miles long, crosses the entire central part of the district in a general N. 30° W. direction (fig. 73). This zone contains all mineable copper deposits, 85 percent of the known copper-bearing lead and zinc deposits, most of the nickel, cobalt, arsenic, and gold occurrences, and the only productive silver occurrence. Lead deposits are present throughout most of the length of the zone, and zinc deposits are in the central part. A barite zone corresponds closely to the central part of the copper zone but is oriented more nearly north-south and, toward the south, it diverges from the larger copper zone. Elsewhere in the district barite is restricted to very small quantities in the lead and zinc deposits. The barite zone contains 90 percent of the localities in which barite is found and includes all of those in which it is abundant. Figure 73 shows that barium, nickel, arsenic, and cobalt minerals are found mostly in the central part of the district and, for the most part, within the central part of the copper zone. A few small isolated mineralized centers that contain small quantities of barite and chalcopyrite lie west of the main copper zone. Barite and chalcopyrite are uncommon and occur in very small quantities in the rest of the district outside of the limits of the main and satellitic zones of these minerals.

The nickel, arsenic, and cobalt minerals are known only in two widely separated parts of the district. One part is in the north, near Linden and Dodgeville, Wis.; the other part is in the south central area of the district near Leadmine, Wis. Both of these local areas of rare minerals are near the centers of the two main areas of zinc deposits (fig. 73).

Both to the east and west of the two main areas of zinc deposits are smaller, less important centers of zinc mineralization. The southern main zinc area extends westward and southward considerably beyond the main copper and barite zones in the southern part of the district, and its southward elongation diverges sharply from these zones. Only a few zinc deposits to the east of the copper zone are known, probably in part, owing to lack of exploration.

Galena is distributed far more widely than other minerals. In fact, the limits of lead deposits are not known to the west, south and southeast, inasmuch as the rocks of the Silurian age and Pleistocene sediments overlap the ore-bearing rocks and hide the edges of the mineralized area. Similarly, the zinc deposits probably are far more widespread than known at the present time. However, they apparently do not extend as far to the east and west as the known lead deposits; furthermore, a true lead zone probably forms the real fringe deposits of the district. For example, to the west at Guttenberg, Iowa (pl. 1), and to the east near New Glarus, Wis., a group of lead deposits probably represent the fringe of lead mineralization. Calcite is the dominant mineral in these deposits, and scattered galena crystals and marcasite are the only sulfides. The minor precipitation of sulfides in the abundant calcite-filled cavities and the extremely simple mineralogy of these deposits are conspicuous. The northernmost zinc deposits, at the outcrop edge of the Platteville and Galena strata at Highland, Wisconsin, contain commercial quantities of zinc, but the proportion of lead in these deposits is very high, averaging 2 percent of lead as compared to 0.5 percent elsewhere in the district. This high lead ratio suggests that the Highland deposits are near the lead zone that probably is the outermost zone of the district on all sides.

Most known ore deposits in the Prairie du Chien group are in the northern fringe areas of the district, and as these deposits are probably affected by the horizontal district zoning, they are mostly lead deposits. It is difficult to obtain a true picture of the relative abundance of lead, zinc and copper minerals in deposits of the Prairie du Chien because nearly all known deposits have been weathered and leached, and relatively soluble minerals such as sphalerite and chalcopyrite have been mainly removed or replaced by oxidation products. Drilling in 1950 by the U. S. Geological Survey (Heyl, Lyons, Agnew, 1951) suggests, however, that sphalerite is commonly deposited in the Prairie du Chien group within the main district, but that galena is more abundant in the northern fringe deposits of this unit.

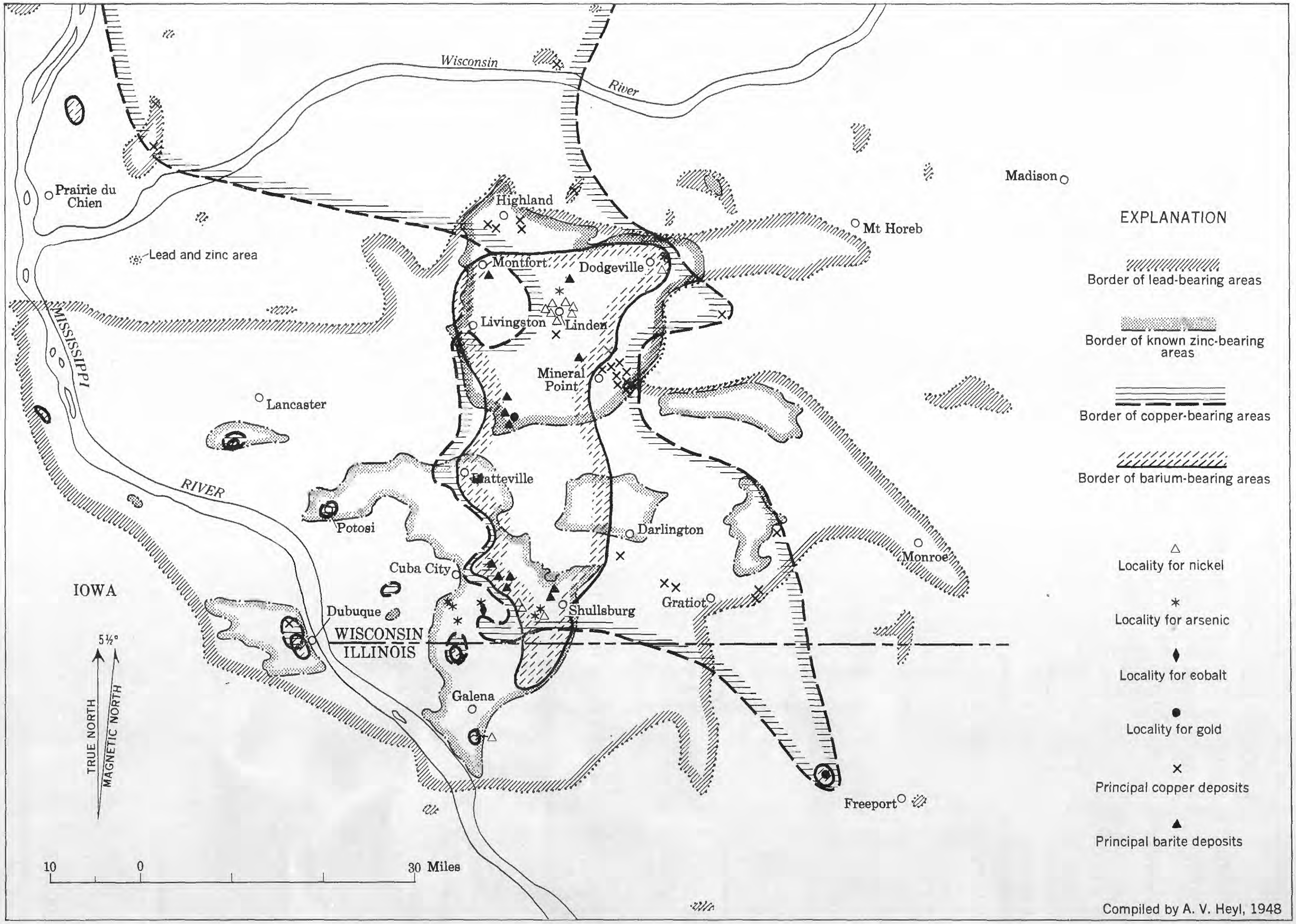


FIGURE 73.—Map of the Upper Mississippi Valley zinc-lead district showing regional zoning of mineralization.

LOCAL HORIZONTAL ZONING RELATED TO CENTERS OF MORE INTENSE MINERALIZATION

A local horizontal zoning is evident within some centers of mineralization in the district. Within each center the concentrations of the several minerals of the deposits differ. Galena, sphalerite, barite, marcasite, chalcopyrite, and millerite show marked variations in their local abundance.

Local horizontal zones of minerals are conspicous in the Linden, Wis. area (fig. 74), where the minerals were studied at 37 mines. The main primary ores are galena and sphalerite with associated marcasite, none of which show much variation throughout this area. However barite, millerite, and chalcopyrite are each restricted to separate, individual parts of the Linden area, and as far as is known the areas containing these minerals do not overlap. Moreover, these minerals are extremely rare or absent in mines in the intervening areas. Barite occurs only in mines north of Linden, where it is an important constituent of the ores. Within the barite zone there is a progressive decrease in the quantity of this mineral toward the south, so that in the three southernmost mines, where it occurs, barite is only a minor constituent. The one known occurrence of arsenic in the ores near Linden is within this barite zone. None of the unusual minerals are found in the ores in a strip half a mile wide to the south and southwest of the barite zone.

The nickel zone, in which all the ore bodies contain some millerite in addition to the main ore minerals, is centered at Linden and extends a short distance to the west and southeast. No barite and only traces of chalcopyrite have been found here, and the nickel zone is bordered closely on all sides by mines that contain no known nickel minerals.

Chalcopyrite was mined in a very small area 1 mile south of Linden. Very few lead or zinc minerals accompany the chalcopyrite, and the zinc ores in nearby mines contain no visible copper minerals.

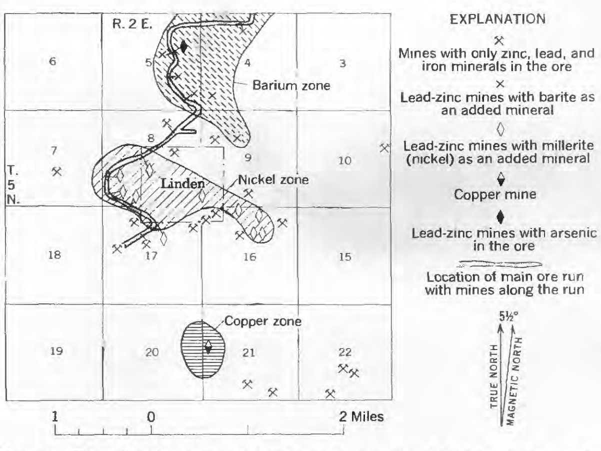


FIGURE 74.—Local zones of minerals in the Linden, Wis., subdistrict. All marks indicate the location of mines.

One unbroken zinc ore body or "run" of many mines extends from the north part of section 4 southward into the west half of sec. 17. Figure 74 shows that the zones of unusual minerals are not related to this ore run, but they cross indiscriminately. Each of these elements occurs in an area separated from the other two elements, and each area lies athwart the zinc run. Furthermore, although the minerals containing these three elements are part of the genetic sequence, each mineral is found in parts of the Linden area other than the main zinc run.

A similar example of local horizontal zoning is recognized at Mineral Point, Wisconsin, a few miles southeast of Linden, in a mineralized center that includes many mines. An area to the east and northeast of the town contains the greatest concentration of copper in the district. The copper ore, in which chalcopyrite is the primary mineral, is associated in large quantities with lead and zinc ores just east of the town, and occurs alone a short distance farther east. Barite is a common to abundant constitutent of the zinc ore bodies in the western part of the Mineral Point center of mineralization, but copper minerals are in very minute quantities or are absent. Conversely, no barite is associated with the ores east of town. The local lateral zoning in the Mineral Point area may be summarized as follows:

West	*Central*	*East*
zinc	zinc	copper
barium	lead	
lead	copper	
trace copper		

Similar local horizontal zoning is known throughout most of the district.

VERTICAL ZONING IN RELATION TO THE ENTIRE MINERALIZED STRATIGRAPHIC SEQUENCE

The vertical zoning of primary minerals that has been observed in the district is somewhat similar to that described from more continuous vein deposits of other mining districts. The minerals showing zoning are sphalerite, galena, quartz, dolomite, millerite and locally iron sulfides. To a limited extent the vertical zonation of the ores has been discussed by other geologists (Chamberlin, 1882, p. 488–491; Grant, 1906, p. 74–75; Bain, 1906, p. 52–53; Bastin et al., 1939, p. 116–117, 136–137). Deposition of only iron sulfides in the St. Peter sandstone apparently is a false vertical zoning, and may be related to the completely different lithology of the sandstone host rock from the limestone and dolomites that normally contain the principal zinc-lead ore deposits. All the zoning is within the carbonate-bearing rocks except for one anomaly. Some of the carbonate rocks are dolomites and others are limestones, and these differences in the composition of the host rocks may also have caused some of the zoning during ore deposition.

The vertical zonal relationship will be described in stratigraphically descending order. The gash-vein lead deposits of the Galena dolomite are of simple mineralogy and contain galena, calcite, with some marcasite and pyrite. Galena is distinctly the dominant sulfide. Less commonly sphalerite accompanies the ores, but almost everywhere it is less abundant than the galena. Locally, chalcopyrite and barite are found in the gash-vein deposits and in the underlying zinc deposits but do not exhibit any vertical zonal relationship within this known range.

The principal zinc deposits of the district occur most commonly in the Decorah formation, but they extend up into the lower part of the Galena dolomite and down into the upper part of the Platteville formation. The main sulfides are sphalerite, pyrite, and marcasite. Galena, although a common mineral, is distinctly a minor constituent of the ores. Millerite, locally a minor mineral in the zinc deposits, has never been found higher than the Decorah formation, and in the north half of the district it has been found only in the Platteville formation. Silica and dolomite, rare minerals in the gash-vein deposits, are abundant in the zinc deposits. These minerals appear in small quantities in the dolomitic upper Decorah and lower Galena strata, and both minerals increase in quantity in the Platteville and lower Decorah. Crystals of quartz and dolomite are rare.

As stated previously, iron sulfides are predominant in the underlying St. Peter sandstones. Quartz, as crystal overgrowths on the original sand grains, is the other important mineral deposited in the St. Peter sandstone, and is the next most abundant mineral to iron sulfides in this formation.

Silica is markedly more abundant in the Prairie du Chien group than in deposits in the Platteville, Decorah, and Galena. Drusy quartz, chert, and jasperoid are the main gangue minerals of these deposits. The silicification was followed by abundant dolomitization of the beds within the areas of the ore deposits. Pink dolomite occurs as widespread replacements and veins in the Prairie du Chien. Calcite, so abundant in the overlying deposits, is uncommon, although some of it may have been removed by leaching. Barite is apparently uncommon.

The sulfides in the known deposits, in the Prairie du Chien, in order of abundance, are galena, pyrite and marcasite, chalcopyrite, and sphalerite. Considerable chalcopyrite was deposited in the north fringe area of the district, but the deposits are on the general trend of the regional copper zone. Possibly the copper deposits are related to the horizontal rather than to the vertical zoning or are different aspects of the same general process.

In summary, the vertical zoning indicates marked increases in dolomite and silica deposition with depth. Calcite deposition apparently was greatest in the main zinc deposits in the lower Galena, Decorah, and upper Platteville formations, and it decreases above and below. Galena is most abundant in the gash-vein deposits at the top of the mineralized section and decreases abruptly in the underlying zinc deposits. Sphalerite increases markedly in quantity from a relatively small amount in the gash-vein deposits to a large amount in the underlying pitch-and-flat zinc deposits. A corresponding change from dolomite to limestone host rocks may provide important chemical differences to cause this zoning. The relative abundance of sphalerite to galena is not yet clear in the rocks beneath the Platteville formation. Pyrite and marcasite appear to increase a little in quantity from the gash-lead veins down into the underlying zinc deposits and continue abundant at greater depths. Millerite is restricted to a thin zone in the Platteville and Decorah formations. No vertical zoning is yet apparent in chalcopyrite and barite deposits.

VERTICAL AND HORIZONTAL ZONING WITHIN INDIVIDUAL ORE DEPOSITS

Individual ore bodies may show indications of horizontal and vertical zoning of galena, sphalerite, pyrite and marcasite, barite, chalcopyrite, millerite, and calcite. The relative abundance of sphalerite generally decreases outward from the main pitches of an ore body, but any or all of the following minerals—galena, pyrite, marcasite, chalcopyrite, barite, and calcite—increase in relative amounts. The pyrite, marcasite, chalcopyrite, and calcite are more marginal than barite and galena, except at the top of the ore body. This type of zoning is present both on the hanging wall and footwall sides of an ore body as well as at its ends. The marginal zone of pyrite, marcasite, and calcite generally marks the horizontal limits of mineable gash-vein and pitch-and-flat ore bodies.

The main zinc ore bodies show vertical zoning. Galena is generally more abundant near the top of the ore body; sphalerite and marcasite increase in relative amounts near the bottom; silica and dolomite are common in the lower parts of the ore body but are rare or absent near the top; millerite occurs only in the lower parts of the deposits. A zone, several feet thick, of abundant iron sulfides, some calcite, but with practically no galena or sphalerite, marks the bottom of pitch-and-flat ore bodies.

ORIGIN OF THE ORES

The origin of the ores of the upper Mississippi Valley zinc-lead district has been a controversial subject for nearly a hundred years. Theories for the deposition of the ores by meteoric and artesian water were developed, and the district is regarded by many geologists as a type area in the study of ore deposits of this nature. Many variations in theories of origin that fit into this general idea of cold water deposition have been advanced, and numerous sources for the metals have been suggested. Previous to the development of the meteoric water theory, the geologists who studied the district considered the ore deposits to have been formed by "emanations" from somewhere in the basement rocks beneath the comparatively thin cover of Paleozoic rocks. Within the last decade a number of geologists have tended to return to this early view.

EVIDENCE FOR THE MAGMATIC HYPOTHESIS

A summary follows of the most pertinent points that support the magmatic hypothesis of the genesis of ores in the upper Mississippi Valley district:

1. The district has definite limits beyond which the same limestone and dolomite beds are barren of ore, even though they contain similar but unmineralized fracture systems favorable for the deposition of ore and minute quantities of lead and zinc equal to those in the district's host rocks. This regional center of ore concentration is most easily explained by a magmatic source beneath the mineralized area.

2. The proposed magmatic source, in the form of a magma of late Paleozoic or Mesozoic age intruded into the underlying basement of Precambrian rocks, would provide an original source much closer to the deposits than the area of Precambrian rocks 200 miles to the north.

3. Known intrusions of Paleozoic and Mesozoic age in many places elsewhere in the Central States make it possible to postulate the existence of igneous intrusions at depth in this area.

4. The geologic study has shown that faults and fractures are abundantly present in the district. These fractures and the known sandstone aquifers provide ample channels to permit the upward and lateral flow of thermal solutions to the present locations of the ore deposits in the Platteville, Decorah, and Galena formations.

5. The complex system of bedding-plane faults, reverse faults and shear faults, plus the aquifers, and the probably impervious cap of Maquoketa shale would all tend to cause a great deal of lateral flow of the solutions in addition to their vertical rise. This lateral flow would tend to distribute widely the solutions and their resulting ore deposits to form the large mineralized district.

6. The deposits of sufides formed by damming of the ore solutions beneath the Maquoketa shale cap are evidence in themselves of rising solutions. Similar damming within the main ore deposits beneath certain impervious beds and faults is likewise evidence of upward-moving solutions. As most of the sulfide stalactitic forms found in the mines point upward, these unusual structures must have been deposited by rising solutions rather than by downward-percolating meteoric waters.

7. The deposits in the upper Mississippi Valley district are not limited to the Galena dolomite, or to strata overlying a shaly "ponding layer", as they were once considered to be. They occur along recognizable faults and fractures and are distributed, at least in some quantity, in all the known rocks within the district from the Upper Cambrian to the Silurian, irrespective of depth. These facts are more in concurrence with the magmatic hypothesis than the meteoric hypothesis.

8. The ores were emplaced in the latter part of a period of mostly tectonic deformation that continued during ore deposition; both processes ceased at approximately the same time. The age relations are very similar to those of hydrothermal ore bodies elsewhere and the tectonic disturbances that produced their controlling structures.

9. The paragenetic relations in the district show a single, relatively short cycle of mineral deposition, unrepeated. The sequence is very similar to the type generally seen in hydrothermal deposits. Most meteoric deposits show many repeated depositions of minerals over a long period of time.

10. The small quantities of arsenic, silver, cobalt, nickel, gold, and molybdenum in the ores suggest a magmatic origin, as these elements are typically in hydrothermal deposits. However, none of the primary minerals of the ore deposits, except perhaps sericite, is diagnostic of either hydrothermal or meteoric origin.

11. The mineralogy of the ores is more complex than formerly recognized, as the ore solutions carried not only lead, zinc, iron, and sulfur ions, but also appreciable amounts of barium, copper, silver, nickel, arsenic, cobalt, cadmium, silicon, magnesium, potassium, sodium, and chlorine. It is difficult to conceive of some of these elements, chemically so dissimilar (for example, silver and barium, arsenic and zinc), being concentrated in unusual quantities and deposited together

by meteoric waters in one limited area the size of the district.

12. The lateral and vertical zoning of the ore bodies, both types of which show definite well-defined mineral zones, are evidence of hydrothermal deposition. The northwestward-trending copper, nickel, barite, and gold zones show a marked independence of local centers of ore body concentration, regional structure, and regional dip, so that they may overlie the general area of the source intrusion. The vertical zoning shows a regular change in minerals with increasing depths, accompanied by an increase of wall-rock alterations, which possibly indicates higher temperatures of deposition at greater depths.

13. The temperature of deposition of the sphalerite, as determined by Newhouse (1933, p. 748) and Bailey and Cameron (1951) from crystal inclusions (80° to 105° C.), is about the same as that of epithermal deposits; and this temperature, though low, is far too high for any conceivable meteoric deposition, even assuming that the now-eroded, overlying beds were 1,000 feet thicker than their present maximum thickness. The orderly, regular decrease in the temperatures of deposition of the older to younger sphalerite and the somewhat lower temperatures of deposition of calcite (Bailey and Cameron, 1951), which was the last mineral to be emplaced, indicate that the temperatures of the ore solutions decreased markedly during the relatively short period of ore deposition, as expected by proponents of the magmatic hypothesis.

14. Saline connate waters are of such extremely local occurrence (only at and near Prairie du Chien, Wis., which is outside the main district) that their former widespread existence within the district is purely hypothetical. Similarly, the small quantities of hydrogen sulfide in the deeper meteoric waters of the district do not prove its former widespread, more concentrated occurrence. Even if such connate waters were formerly of widespread occurrence, they would also have had to contain considerably greater quantities of hydrogen sulfide than recorded to provide enough sulfur to precipitate the sulfide ores.

15. The evidence of Newhouse (1932, p. 419–436) indicates that the solutions depositing the ores contained concentrations of $Na+$ and $Cl-$ far greater than could possibly be present in meteoric waters or in the only known saline, connate waters in the district. But the concentrations of $Na+$ and $Cl-$ are in essential agreement with the amounts of these ions generally found in hydrothermal solutions and volcanic emanations.

16. The transport of the main metals of the ores of the district in hydrothermal solutions in balance with the chloride radicle involves no serious chemical difficulties (Bastin and others, 1939, p. 133).

17. Chemical studies (Bastin and others, 1939, p. 139–140) show that precipitation of lead sulfide from rising solutions is possible nearer the surface, and farther from the magmatic source, than the greatest concentrations of zinc sulfide. This deposition could occur in the type of solutions and under the conditions expected by supporters of the hydrothermal theory.

18. Although large volumes of the limestone and dolomite wall rocks in the ore bodies were dissolved during ore deposition, and these rocks contained minute quantities of lead and zinc, the volumes dissolved are still much too small to supply the quantities of these metals concentrated in the ore deposits.

Much larger volumes of metals have been carried away in surface and meteoric waters and lost as the rocks of the district have been eroded. Precipitating agents necessary to redeposit these metals are not known in the surface or meteoric waters, or in their host rocks below the water table. The sparsity of caves, solution channels, and karst topography in the district suggests that the carbonate rocks have been much less dissolved below the zone of weathering than in many other similar areas.

HISTORICAL RÉSUMÉ

The earliest visitors to the district, such as Featherstonhaugh and Schoolcraft, recorded little of their ideas as to the origin of the ores. A few vague references indicate that they accepted the prevailing ideas that the ore deposits were formed from deep-seated ascending waters.

PROPOSAL OF THE MAGMATIC HYPOTHESIS

The geologist who made the first extensive study of the district was David Dale Owen (1848, p. 22–23). He briefly discussed the problem of origin of the ores and concluded that their source was in the underlying basement of granitic and crystalline rocks.

The first annual report of the Geological Survey of Wisconsin, written by Edward Daniels (1854, especially p. 31), was published in 1854. He proposed that the ores were deposited by a combination of the four different methods then advocated for ore deposits generally; he favored a combination of the last three methods:

1. The mineral matter, dissolved in water, filtered from above into the crevices.

2. The metallic ores were molten and injected into the rocks by subterranean forces.

3. Sublimation—the introduction of the metals in the state of a heated vapor that cooled, condensed, and formed veins.

4. Electro-chemical action, apparently in solutions,

is supposed to have caused a segregation of metallic particles and thus formed the veins.

The next year James G. Percival (1855, p. 100) briefly expressed his views on the origin of the ores, and he was in agreement with Owen. Percival's views are quoted below:

The appearances seem no less to indicate the origin of the mineral and the accompanying ores from beneath, probably from the primary rocks underlying the lowest secondary; and that they rose in such a condition that they differed through a certain definite extent of the materials of the rocks, and then segregated in their present form, and this along certain lines that have determined their arrangement. It would be premature to offer a theory until a more complete exploration had been made, and all important facts which such exploration might offer were collected and arranged. But even now I have a strong impression that the mineral has been derived from beneath, and that the prospects of deep and continued mining are here as favorable as in other more established mining districts.

PROPOSAL OF THE METEORIC HYPOTHESIS

In sharp antithesis to the views of Owen and Percival is the meteoric hypothesis first advanced by J. D. Whitney (1862, p. 388–402). As a result of several years' study of the district, he concluded that the metals were originally precipitated in the sea at the time of the deposition of the rocks, and were later concentrated in the present ore deposits by re-solution, transportation, and deposition by ground water; a process he termed "lateral secretion." Whitney suggested that Ordovician seas contained unusual amounts of the metals and that organic matter originally precipitated the minerals from the sea water. Further concentration of the metallic constituents into ore deposits was explained as produced by the unusual amounts of organic material in the rocks.

The most important contribution to the development of the meteoric hypothesis of deposition was made by T. C. Chamberlin (1882, p. 522–553).

His conclusions were based on those of Whitney, whose theory he advanced in much greater detail. On the fundamental question of the source of the material, Chamberlin suggested that the minerals of the ore deposits were originally derived from the crystalline rocks in the Wisconsin dome toward the northeast and were disseminated through the Platteville, Decorah, and Galena by circular ocean currents forming an eddy during sedimentation. Moreover, a calculation showed that the lead and zinc required in primary sediments to produce the richest known ore bodies by meteoric concentration was very small (0.14 percent). The eddy was thought to be unusually favorable for the accumulation of organic matter, particularly of plant remains, with consequent reduction and precipitation of the sulfides.

The deposits in synclines within the district were localized by accumulation of the metals in depressions of the sea floor, which were considered to have furnished especially favorable conditions not only for original precipitation but also for later further concentration of the minerals into ore deposits.

Chamberlin described vertical zoning of the deposits, galena above and sphalerite below, and suggested that this zoning resulted from a process of "selective chemical affinity."

DEVELOPMENT OF VARIATIONS IN THE MAGMATIC AND METEORIC HYPOTHESES

In 1893 W. P. Jenney (1894, p. 171–225) discussed the origin of the ores in this district and in Missouri. He stated (Jenney, 1894, p. 184) "a general law" that

all workable deposits of ore occur in direct association with faulting fissures traversing the strata, and with zones or beds of crushed and brecciated rock, produced by movements of disturbance. The undisturbed rocks are everywhere barren of ore.

Inasmuch as he considered the mineralized vertical joints to be shear faults of considerable displacement, he thought that these faults were continuous at greater depths and therefore were the feeding fractures of the deposits. Jenney related the deposits to uplift of the Wisconsin arch and to local disturbances in the strata; noted a regular paragenesis of the ores; and described vertical zoning of sphalerite below and galena above.

He discussed the origin of the ores as follows (Jenney, 1894, p. 214):

The evidence obtained in this investigation indicates that the ores and the associated minerals have all been deposited from aqueous solutions, probably of moderate or normal temperature and pressure, and that the fissures connected with the ore bodies have formed channels through which the mineralizing waters were introduced. It is also evident that the lead and zinc were not derived from the geological formations in which the deposits occur, or from the overlying or underlying sedimentary strata, but that the source of the metals was exotic and probably deep-seated in the primitive rocks.

He suggested that the ores were deposited during the period of Laramide orogeny.

W. P. Blake (1893, p. 621–634), who had spent 2 years in the district as a mining geologist, led the discussion of Jenney's paper. He agreed with Jenney that the deposits were localized by faulting and brecciation but disagreed with his theory of the origin of the ores. Two papers by Blake (1893a, p. 25–52; 1893b, p. 558–568) present his conclusions (1893a, p. 31):

1. That faults and dislocations exist in the Wisconsin lead and zinc region, and that these faults have a direct, though obscure, relation to the localization of the mineral deposits, as claimed by Percival.

2. Although it is not probable that the faulting

planes gave vent to mineral solutions from below, they probably permitted the outflow of fresh water or of gases which acted upon the sea-water as precipitants of the metals and also as destroyers of the animal and vegetable life in their vicinity, by the decomposition of which organisms the accumulation of metallic sulfides in the rocks was promoted and to some extent localized.

3. * * * [The] "oil rock" is at the base of most of the zinc deposits, and appears to have acted both as a retentive substratum, or floor of deposition, of blende and as a source of deoxidizing and of sulphurizing gases which have determined the reprecipitation of the zinc from the sulfate solutions derived from the oxidation of the blende deposits above the water level. [Elsewhere he stressed the impervious character of the oil rock and clay bed, which prevents deposition of these ores below them.]

4. That the arrangement of the crevices indicates a shattering of the strata, especially of the compact vitreous limestones of the lower Trenton, called "glass rock" * * *.

5. That the coincidence in extent of the lead and zinc region with the "Driftless Area," * * * and the absence of ores in the glaciated areas tends to show that the ores have been derived from the mass of rocks by gradual oxidation, secretion and lateral flow into the fissures during the geologic ages to which the rocks were exposed to atmospheric agencies.

6. That the chemical conditions favoring the deposit of zinc ores and lead ores appear to have been worldwide and most favorable when the ancient * * * [Ordovician and] Silurian rocks were laid down.

Winslow (1894) in his comprehensive report on lead and zinc deposits concluded that the Ozark ores were altogether formed by secondary processes. He believed them to have been concentrated by descending meteoric solutions from decomposition and erosion of overlying beds. He suggested that this theory might also be applicable to the deposits of the upper Mississippi Valley district. He noted the wide distribution of lead and zinc, and at his suggestion J. D. Robertson made quantitative analyses of a large number of samples of rocks of the Ozark region (Winslow, 1894, p. 480–481). The "limestones" (including dolomites) contain an average content of 0.00027 to 0.00346 percent lead, 0.00016 to 0.01536 percent zinc, and 0.00012 to 0.00880 percent copper. Slightly larger percentages of the metals were found in the crystalline rocks of the Ozarks, but the analyses were not considered numerous enough to establish the larger quantities as a rule.

In 1896, A. G. Leonard (1896, p. 57–65) discussed the origin of the upper Mississippi Valley ore deposits. He pointed out that the presence of the thick, impervious Maquoketa shale in much of the Iowa part of the area presented difficulties in accepting Winslow's explanation that the ores were derived from the overlying beds. He adopted Chamberlin's explanation of the origin and localization of the ores, stating (p. 61) that "it furnishes on the whole the most plausible explanation yet offered for the localization of the Upper Mississippi deposits."

In the Iowa Survey's report on Dubuque County, Calvin and Bain (1899, p. 566–581) described the ore deposits in Iowa. They accepted most of the conclusions of Whitney and Chamberlin. They checked the presence in the country rock of lead and zinc in very small quantities by quantitative analyses like those made by Winslow, and they noted the close association of the deposits with dolomite. They suggested that the conditions that produced regional dolomitization of the Galena were favorable to the original precipitation of the metals from sea water.

PROPOSAL OF THE ARTESIAN CIRCULATION HYPOTHESIS

In 1900 Van Hise (1900, p. 27–177) discussed the general principles controlling the deposition of ores and applied them to the deposits of the upper Mississippi Valley district. This paper advanced an entirely new variation of the meteoric hypothesis. The theory of the derivation of the ores from the crystalline basement exposed to the north was accepted. The first localization of the ore minerals was hypothesized on a wholly new basis, namely, that they were deposited around the outlets of former artesian circulation channels of meteoric waters from the north into the district. The aquifers suggested were the St. Peter sandstone and sandstones of Cambrian age that were continuous southward-dipping strata from their outcrop area in central Wisconsin around the Wisconsin dome. Material that had been widely diffused through the region to the north was first concentrated in southwest Wisconsin by the artesian circulation. The present ore deposits were formed by secondary concentration by downward and lateral secretion from the older lean artesian deposits, essentially in the manner postulated by Chamberlin. The present vertical zoning of the deposits was explained as a result of secondary meteoric enrichment. This paper attracted wide attention, and the theory was widely applied to other deposits, particularly those of the Tri-State district (Van Hise and Bain, 1902, p. 376–433; Siebenthal, 1915).

GENERAL ACCEPTANCE OF THE METEORIC AND ARTESIAN CIRCULATION HYPOTHESES

In 1902 U. S. Grant commenced a study of the Wisconsin part of the district for the Wisconsin Geological

Survey. In 1903 he (Grant, 1903, p. 77–87) published a preliminary report in which he accepted Van Hise's conclusions regarding the genesis of the ores. He did state, however, that there was "good reason for believing that the first ores of the district were deposited by deep-seated circulating waters," and he assigned to this type the deposits that have a regular order of mineral deposition. These deep-seated waters he considered to have moved in artesian circulation as described by Van Hise (1900). He then stated that surface concentration by descending meteoric waters probably added to these original deposits and caused the disseminated ore bodies.

In 1906 the Wisconsin Survey published a second report on the district by Grant (1906, p. 77–79), and by this time he had changed his opinions considerably, returning to the original Chamberlin hypothesis of oceanic deposition with the limestones and later concentration by lateral and descending meteoric waters. The original source was considered to be the Precambrian crystalline rocks to the north.

In the same year the United States Geological Survey published a paper on the district by H. F. Bain (1906, p. 124–125). He had modified some of his former views (Calvin and Bain, 1899, Van Hise and Bain, 1902) and discussed the origin in greater detail. He rejected the theory of deep-seated origin for the ores and, like most other geologists at that time, considered the original source of the zinc and lead to be the crystalline rocks of the Lake Superior region. Like Chamberlin, Bain considered these metals to have been carried into the sea during the process of erosion of the ancient land mass to the north and to have been deposited in minute quantities in the sedimentary rocks over a widespread area. He considered that any original localization of the ores might have been caused by:

a. Local abundance of metals in solution.
b. Local abundance of organic reducing matter.
c. Locally peculiar organic matter unusually efficient in producing precipitation.

He attached particular significance to the carbonaceous material in the "oil rock." The local concentrations of "oil rock" in basins he considered to be the result of deposition of the carbonaceous shales in original depressions in the sea floor.

He considered that reconcentration by secondary processes was of prime importance in producing the present ore bodies. This secondary concentration, according to Bain, was due to two separate types of meteoric water movements; (1) lateral movements of artesian currents below the water table, and (2) descending surface waters. The mingling of these two types was considered sufficient to precipitate the metals into the ore bodies. He emphasized the presence of the impervious shale layers at the base of the Galena (now Decorah) formation, which he thought prevented the upward flow of solutions.

In 1907 the Lancaster-Mineral Point folio was published (Grant and Burchard, 1907, p. 12). It reiterated Grant's earlier views with special emphasis on the impervious "oil rock" (Guttenberg) and so-called clay bed (Spechts Ferry).

In 1914 the Illinois Geological Survey published a report by G. H. Cox (1914, p. 63–100) on the Illinois part of the district. Cox discussed at great length the origin of the ores. In a general way he returned to the ideas of Winslow, for he considered the main source of the ores to be the eroded Maquoketa shale that formerly overlay the Galena dolomite throughout the district. He also suggested that the original source of the ores was the crystalline rocks of the Lake Superior region. These metals were transported by streams into the sea, and deposited in small quantities as a part of the Maquoketa shale. Reduction by organic matter precipitated the ores into these shales. As the shales were eroded, these particles were taken into solution by descending meteoric waters, carried downward, and redeposited in the Galena dolomite.

Shaw and Trowbridge (1916, p. 11–12) were the authors of the Galena-Elizabeth Folio covering the Illinois part of the district. From their summary statement it is evident that they were in complete agreement with the later views of Grant (1906) and Bain (1906), which in turn were essentially the same as those originally formulated by Chamberlin (1882, p. 552–553).

RETURN TO THE MAGMATIC HYPOTHESIS

In 1924 a paper on the upper Mississippi Valley district by J. E. Spurr (1924, p. 246–250; 287–292) appeared; his theory of origin was very similar to that of Percival. Spurr's hypothesis, which was formulated mainly from the literature and from a very brief visit to the district, returned to the idea of a magmatic origin for the ores. His evidence for this was a supposed pattern of the main mineralized centers in ore-bearing belts very similar to those advocated by Percival. These belts trended northeasterly and northerly. He related the district fractures to hypothetical subterranean intrusions of about the same trends as the ore zones. Intrusions were supposed to have been followed by subsidence and contraction that produced two sets of fractures, one parallel to and the other at right angles to the trend of the intrusions. These fracture systems were presumed by Spurr to be the feeders along which the hydrothermal solutions from the intrusions passed upward into the beds in which the ores were deposited.

Several years later W. H. Emmons (1929, p. 221–271) suggested a hydrothermal origin for the ores of this and the other Mississippi Valley deposits, and his concepts were based on regional zoning and structural relationships. He pointed out the presence in the upper Mississippi Valley district of a copper zone surrounded by zones of lead and zinc ores without appreciable copper. He related the district to the north end of the LaSalle anticline, which he thought extended through the district in a northwest direction. He showed that the copper zone was parallel to, and on the trend of the LaSalle anticline. He considered minor faulting to be present along this supposed zone of deformation, and noted the presence of vertical zoning in the deposits. These structural and zonal relationships were considered to support the hypothesis that the ores were deposited by rising thermal waters whose source was in a deep-seated igneous mass.

Fowler and Lyden (1932, p. 206–251) published the first paper based on their intensive studies of structure and ore deposits in the Tri-State district of Missouri, Kansas, and Oklahoma. They noted a controlling system of shear zones and faults in these states and considered the fracture systems to continue at depth. For these reasons, plus the regular paragenesis of the ores, they favored a hydrothermal origin of the ores in the Tri-State district.

Weidman (1932), in his report on the Oklahoma part of the Tri-State district, agreed with many of the ideas of Fowler and Lyden in regard to the deformational fracture system, and he also favored a hydrothermal origin of the ores.

C. K. Leith (1932, p. 405–418) published a paper on the structure of the Tri-State and upper Mississippi Valley districts and its bearing on the origin of the ores; in it he defended the previously widely accepted meteoric hypothesis. He considered that both the "oil rock basins" and the associated fractures of all types could be explained largely by original deposition and differential slumping of the rocks.

Newhouse (1932, p. 419–436) reported on the composition of vein solutions as shown by liquid inclusions. A second paper by Newhouse (1933, p. 744–750) concerned the temperature of formation of the Mississippi Valley lead-zinc deposits. He believed that certain types of liquid inclusions in minerals represent samples of the solution that deposited the minerals. The fluid inclusions in galena and sphalerite from this district and from known hydrothermal deposits contain similar amounts of sodium, calcium, and chlorine. The concentration of the sodium chloride in the inclusions tested was from 12 to 25 grains per 100 cubic centimeters, far above that of normal sea water or connate water. Newhouse pointed out (1) that this concentration of sodium chloride in these solutions excludes the possibility of the formation of the ores by meteoric and artesian waters, (2) that the similar composition of these solutions to those of known hydrothermal origin points to the fact that the Mississippi Valley deposits are also of hydrothermal origin, and (3) that the temperature of formation of the sphalerite was from 80 to 105 degrees centigrade, slightly lower than of most other Mississippi Valley ores. This temperature is, however, in agreement with the colloidal deposition postulated for some of the ores of this district.

Banfield (1933, p. 123–133) made a microscopic study of the ores. He favored the meteoric theory of origin by lateral secretion and descending waters as the most adequate hypothesis to explain the many features of the ore deposits.

In 1935 C. H. Behre, Jr. (1935, p. 377–382; especially p. 381) stated that he considered the ores to be deposited by rising hydrothermal solutions. His reasons are given here in only a very brief summary:

1. The presence of faults that could act as solution channels.
2. The deposits are zoned vertically similar to those of igneous origin.
3. The work of Newhouse, who found indications by his studies of the inclusions in the minerals that the temperature of deposition was greater than 80 degrees centigrade.
4. Small quantities of arsenic in the ores.

Lindgren (1935, p. 463–477) discussed, to a certain extent, the origin of the ores based on general principles. He noted the tendency at that time to minimize the importance of meteoric waters, and he considered it to have gone too far. The "telemagmatic" lead-zinc deposits of the Mississippi Valley, he concluded, were formed by mixtures of magmatic and meteoric waters, were generally saline, were formed, as shown by Newhouse, at comparatively low temperatures, and are most closely related to the epithermal deposits.

Also in 1935 Graton and Harcourt (1935, p. 800–824) published a study of rare elements in the ores of the Mississippi Valley "type," and they related this evidence to the hydrothermal origin of the ores. They noted in the ores of the Tri-State district the presence of small amounts of copper, lead, silver, bismuth, antimony, cadmium, gallium, germanium, and indium. They found a notable correspondence in the amounts of cadmium, gallium, germanium, and indium in the Mississippi Valley ores and in known hydrothermal deposits. The content of minor metals is exactly as might be expected theoretically in low-temperature hydrothermal deposits. They also noted in the ores other elements such as cobalt, nickel, arsenic, molybdenum, chromium, vanadium and tungsten, and pointed out the similarity of the "jasperoid" type of silica deposit to silica deposits of shallow epithermal veins elsewhere. They considered the scantiness of known exsolved chalcopyrite in the ores an indication of telethermal origin. Although their paper does not refer directly to the Upper Mississippi Valley district, much of their data are also applicable there.

A paper by Behre, Scott and Banfield (1937, p. 783–809) presents mainly Behre's views on the origin of the ores, and his interpretation that the ores are of hydrothermal origin. Behre pointed out that the type of fracture system in the district would make it improbable that the solutions rose in a straight line, and that the solutions probably moved laterally and chiefly upward and followed the numerous discontinuous small fractures. He showed that ore has been found below the supposedly impermeable beds and therefore that these beds probably did not prevent movement of solutions. He stated that the chemical and mineralogic data of more recent work make deposition by descending waters the more difficult hypothesis. The vertical zoning in the district was thought by him to be typical of hydrothermal deposits. He suggested that unstable marcasite and wurtzite inverted to more stable pyrite and sphalerite after deposition.

In 1939 an excellent paper summarized the views of the many men who studied the Mississippi Valley ore deposits (Bastin and others, 1939, p. 121–153). In this paper Bastin and Behre felt the balance of evidence was in favor of the hydrothermal theory of origin.

R. M. Garrels (1941, p. 729–744) discussed the chemistry of the ore solutions and its relation to mineral zoning of the ores. He discussed the unusual vertical lead-zinc zoning of the deposits where the lead is more abundant above the zinc, and the chemical conditions of deposition needed to prevent lead from precipitating before zinc. Garrels considered most ores of the Mississippi Valley type were deposited under conditions of chemical equilibrium and that a liquid phase was present. Under such conditions of deposition the type of zoning observed would be possible. He suggested that concentrated chloride solutions could have been responsible for the apparently anomalous primary zoning of galena and sphalerite. He believed that zoning problems in shallow deposits of hypogene origin must be explained on the basis of either concentrated solutions or solutions in unstable equilibrium.

In 1945 H. B. Willman (1945, p. 96–97) discussed the structure of the ore deposits. He noted breccias formed before mineralization in the pitch-and-flat deposits and beds thinned by solution during and after mineralization. These observations suggested to him that solution, deformation, and mineralization were contemporaneous, at least in part. He also believed in the hydrothermal origin of the ores (written communication to Heyl, December 1945).

SUMMARY

The ideas of origin of the ores in the district can be classified into two concepts: (1) the magmatic hypothesis, (2) the meteoric hypothesis. The magmatic hypothesis proposes that the source was a magma beneath the deposits, from which rose ore-bearing emanations (most commonly considered to be hydrothermal solutions) that deposited the ores. The meteoric hypothesis suggests that the ores were deposited from meteoric waters. It has been further subdivided into two subconcepts: (a) lateral secretion and descending meteoric waters, and (b) rising artesian meteoric solutions, followed by reconcentration by lateral secretion and descending waters.

Table 7 lists the geologists who studied the district according to the hypotheses they favored. The publications in which they presented their ideas are given in the bibliography.

TABLE 7.—*Chronological list of geologists and the hypotheses they upheld on the origin of the ores*

Date	Magmatic hypothesis	Meteoric hypothesis		Other
		Lateral and descending solutions	Artesian solutions	
1852	Owen			
1854				Daniels
1855	Percival			
1862		Whitney		
1882		Chamberlin, T. C.		
1893		Blake		
1894	Jenny	Winslow		
1897		Leonard		
1899		Calvin and Bain		
1900			Van Hise	
1902			Van Hise and Bain	
1903			Grant	
1906		Grant		
1906		Bain		
1914		Cox		
1915			Siebenthal	
1916		Shaw and Trowbridge		
1924	Spurr			
1929	Emmons, W. H.			
1932	Fowler and Lyden			
1932		Leith, C. K.		
1932	Weidman			
1932	Newhouse			
1933		Banfield		
1935	Behre			
1935	Lindgren			
1935	Graton and Harcourt			
1939	Bastin and Behre			
1945	Willman			

This table shows that the geologists who supported the meteoric hypothesis outnumber those who favored the magmatic hypothesis. Although the magmatic or hydrothermal hypothesis, first proposed to explain the origin of the ores, was long in disrepute, results of the more recent studies in the district have led many geologists to return to it.

DISCUSSIONS OF THE ORIGIN OF THE ORES

The origin of the ores by deposition from hydrothermal solutions has been supported by practically all of the evidence of genesis obtained during the present study. The writers believe that the balance of the evidence is now on the side of the magmatic hypothesis, although it cannot be considered as absolutely proved. If some of the geologic pecularities of the ore deposits that have little bearing on ore genesis are not considered, the similarity of these ore bodies and their veins to those of proved hydrothermal districts is quite apparent.

However, the question cannot be considered closed, and the writers are well aware of the limitations of the evidence. A great deal more knowledge of the mineralogy, temperatures, and chemistry controlling deposition, of the source of the solutions, and of the geology in the hitherto unexplored rocks beneath those known is necessary before the origin of these ores can be demonstrated beyond doubt.

The meteoric and magmatic hypotheses are given below in some detail, so that the reader may more fully understand the evidences for and against both hypotheses. Some repetition of information previously given is necessary to more clearly compare the two hypotheses.

METEORIC HYPOTHESIS

The meteoric hypothesis as proposed by Whitney (1882, p. 388–402) and later advanced by Chamberlin (1882, p. 512–553) assumes the ores were concentrated in their present deposits from minute disseminations widely scattered in Paleozoic sedimentary rocks that are now or were formerly present in the district. This assumption is based on the further assumption that the metals were originally supplied in solution to the seas in which the sediments were accumulating during the erosion of the land mass of Precambrian rocks in the northern part of Wisconsin and farther north. As the Precambrian rocks now exposed in northern Wisconsin are not known to contain lead and zinc deposits of any consequence, it is necessary to postulate either that the now eroded parts of these rocks were notably richer in lead and zinc, or that inconspicuous disseminations of lead and zinc in the rock-forming minerals, detectable for the most part only by chemical analysis, constituted the chief source of these metals.

Analyses of both Paleozoic and Precambrian rocks show minute quantities of lead and zinc in nearly all rocks practically everywhere in the world, and these quantities are slightly larger for rocks of Precambrian age. The quantities are in the order of a few thousands of a percent (Winslow, 1894, p. 479). As the solutions carrying the metals from the Precambrian rocks to the sea were undoubtedly further diluted during erosion and transportation by streams, the meteoric theory postulates a reconcentration and then precipitation from the still very dilute metal solutions in the sea itself into the sediments that were being deposited. This precipitation is postulated to have occurred only in the limited area of the district. The hypothesis requires that this precipitation within the local area continued over a great length of time, and that conditions remained favorable for precipitation in order to scatter the disseminations fairly evenly through the sedimentary beds. To support this hypothesis Calvin and Bain (1899, p. 566–570) and Chamberlin (1882, p. 538) had analyses made of the local rocks and found that they contained a few thousandths of a percent of lead and slightly less zinc. They considered these analyses to be indicative of the very small quantities that were deposited on the sea floor and later concentrated again to produce the ore bodies. They also noted similar minute quantities of these metals in present sea water. They gave this data to show that very minute quantities of lead and zinc have been and are being transported into the seas by streams and precipitated in the sediments during their deposition.

Whitney (1862), Chamberlin (1882), Blake (1893), Leonard (1897), Calvin and Bain (1899), Grant (1906), Shaw and Trowbridge (1916), and Leith (1932) all considered the metal disseminations to exist in the Galena dolomite in quantities a little more abundant than normal. However, Winslow (1894) thought that the disseminations were mainly concentrated in the now-eroded upper Ordovician and Silurian strata. Cox limited them to the Maquoketa shale. In these rocks the metals are assumed to have been present in part, at least, as sulfides, and the sulfur in the present ores was considered to have its source in these older disseminated sulfides.

Surface waters sinking into the ground have been postulated by these men as the agency that, in conjunction with the atmospheric gases, dissolved the slightly concentrated disseminated sulfides of syngenetic origin from the rocks of the district and reprecipitated them in more concentrated form as ore deposits, commonly at greater depths. The metals were presumed to have been transported mainly as sulfides, but Cox (1914, p. 95) suggested that they may have been transported in part in balance with the carbonate or bicarbonate radicle.

Van Hise (1900), and for a time Bain (Van Hise and Bain, 1902) and Grant (1903), believed that the metals were originally deposited in disseminated form in the older formations to the north of the district, and that, as the Maquoketa and Galena cover was eroded off progressively southward down the regional dip of the beds, artesian circulation was set up flowing from north to south. In the south these solutions rose into beds of the Galena dolomite, and upon entering them precipitated the metals as more concentrated sulfides. Descending meteoric waters and lateral secretion were considered to be the agents which caused the final concentration and redeposition of the sulfides into mineable deposits. This artesian theory necessitated many concentrations and redepositions of the ores, as the zone of artesian circulation advanced southward with the southward advance of the erosion of the upper beds, gradually building up the concentrations of the deposits. The artesian solutions were considered to have moved through hundreds of miles of beds, from the Precambrian dome area to the present district, over a long period of time.

Gravity is proposed as the sole motivating force for the circulation of the mineralizing solutions in both the lateral secretion and artesian subconcepts of the meteoric hypothesis. However, Chamberlin (1882) postulated ocean currents in the Ordovician sea as the main mode of transportation from the crystalline rocks to the present area of the district, hypothesizing a "Sargasso sea" area of stagnation as the locus of syngenetic concentration and percipitation of the ores in the district.

In the artesian theory the lateral components of flow under gravity are predominant over the vertical components, and the lateral flow was considered to be controlled in direction by the southwestward regional dip of the beds (Van Hise, 1900).

Such an artesian circulation is known to exist in the Ozark region particularly along the northwestern, western, and southwestern flanks of the Ozark uplift, and the waters there are prevailingly saline (Siebenthal, 1915). In Wisconsin, however, a circulation of this nature has never been proved, and the waters from wells into the deeply buried rocks are not notably saline. The one exception occurs locally at Prairie du Chien, Wisconsin where saline waters, probably connate, have been trapped in the Dresbach sandstone of Cambrian age (Strong, 1882, p. 61–62). Some consideration must be given by those who favor a hydrothermal origin to the possible existence in the past of widespread saline, connate waters in the deeper beds of the district.

Several methods have been suggested for the precipitation of the ores from meteoric solutions, in which the metals are held in equilibrium with sulfate, chloride, carbonate, and bicarbonate radicles. Precipitation caused by the carbonaceous organic matter of the shale in the Quimbys Mill member of the Platteville formation and the Guttenberg member of the Decorah formation has been suggested repeatedly. If the metals are held in solution as sulfates, the reducing action of the organic matter would cause them to be precipitated as sulfides.

Another suggested means of precipitation is by the action of hydrogen sulfide. The deeper waters in parts of southern Wisconsin contain somewhat greater quantities of hydrogen sulfide than those near the surface (Grant 1903, p. 83). The reaction that precipitates sphalerite and galena may be expressed as follows:

$$Zn\,SO_4 + H_2S \rightarrow ZnS + H_2SO_4$$
$$Pb\,SO_4 + H_2S \rightarrow PbS + H_2SO_4$$

Grant considered that precipitation by carbonaceous material or hydrogen sulfide accounted for considerable quantities of the ores.

A further method of precipitation, sometimes mentioned (Bain, 1906), is the mingling of solutions of different composition from different sources. Evidence cited for this process was the larger quantities of ore deposited at intersections of fractures, especially in the lead-bearing joints.

Another mode of concentration was supposed to have taken place when erosion had progressed far enough that the upper part of a fracture in which the metallic sulfides had been deposited was brought within the belt of weathering and oxidation. The zinc and iron, and to a slight extent the lead, went into solution in the surface waters and descended to below the water table where lead, zinc, and iron would tend to be precipitated in that order because of their respective affinities for sulfur.

Possibly zinc sulfide and iron sulfides below the water table may have acted also as means of precipitating lead sulfide, according to reactions suggested by Grant (1903, p. 83). Where marcasite coats sphalerite or galena below the water table, the marcasite was considered by Grant to be a secondary deposit by descending waters, whereas at least some of the other sulfides were thought to be deposits formed by the original ascending circulation.

The localization of the present ore deposits was considered to be caused by two geologic features in the district:

1. The fractures within the "oil rock" basins, but with shaly rocks at the Platteville-Decorah boundary acting as an impervious floor in the basins and ponding the solutions above them;

2. Greater thicknesses of "oil rock" shale within the basins were emphasized by Bain (1906, p. 134–136), and

were supposed to have caused increased precipitation of ores in the basins. Bain considered the "oil rock" as being concentrated during original sedimentation in very gentle hollows in the sea floor.

DIFFICULTIES OF THE METEORIC HYPOTHESIS

Some of the more obvious difficulties of the meteoric hypothesis are discussed below based on the evidences presented by the various proponents of this hypothesis.

The postulated ultimate source of the metals in the Precambrian rocks of northern Wisconsin is purely hypothetical, and based on no direct evidence. No analyses of the lead and zinc content of the rocks are given and the area contains no known lead and zinc deposits of any size. The minute quantities of metal present in these crystalline rocks probably are in the same order of magnitude as Clarke's average for igneous rocks (Clarke, 1924, p. 29). The quantities of these metals, therefore, are probably no greater in the postulated source area in northern Wisconsin than in many other regions of igneous rocks, whose derived sediments are barren of workable ores. As iron and copper are abundant in this area, and as both are easily soluble in meteoric waters, the question then arises as to why the deposits of the district contain only relatively very small quantities of copper, and also iron in amounts only about equal to those of lead and zinc.

As the limestones and dolomites in which these metals are supposed to have been redeposited in disseminated form contain in the district even smaller quantities of these metals (Calvin and Bain, 1899, p. 566–576), and as these quantities are no larger than are commonly found in similar sedimentary rocks elsewhere at the earth's surface, the question then arises as to why the ore bodies were localized in this relatively small district and do not occur also in the large surrounding barren areas.

The presence of minute quantities of these metals in both Precambrian and Paleozoic rocks can scarcely be cited as evidence for or against the meteoric hypothesis. It merely offers a possible ultimate source for the ores from which weathering might have derived material later to be deposited in the superjacent limestone.

The meteoric hypothesis postulates a minimum of two successive disseminations, first in the Precambrian rocks and second in the Paleozoic sedimentary rocks. The artesian concept proposes several more depositions of disseminated lead and zinc minerals in the Paleozoic rocks as the metals were carried southward through them by artesian circulation. The transportation and redeposition processes require not only most of geologic time since the Precambrian, but also the erosion of considerable thicknesses of source beds to accomplish the concentration from sparsely metallized rock to ore. A result of the process would apparently be successively smaller total quantities of ore deposited, because at least some of the metals originally available would remain inaccessibly locked in uneroded parts of the source beds. Probably the minute quantities of lead and zinc recorded by Calvin and Bain represent such locked metal content, as their samples very likely were taken from outcrops or quarries above the water table.

The solution of lead and zinc by surface and meteoric waters presents problems not as great as some other phases of the theory. Large quantities of these metals would be irretrievably lost by being dissolved by surface waters, and then washed away in the streams. Some of the remainder would be carried in solution downward by the meteoric waters, to be redeposited near the water table. The sulfides of iron, copper, zinc, and lead can all be dissolved during weathering, but at different rates depending upon inherent differences in their solubility and the composition of the meteoric waters. Copper and zinc sulfides readily go into solution as highly soluble sulfates. The sulfides of iron also readily dissolve as sulfates, but large quantities of the metal are then immediately redeposited as iron hydroxides and oxides. The remainder of the iron content probably descends in solution with the meteoric waters.

However, the solution of lead sulfide is more difficult. It changes to lead sulfate, of low solubility, and this sulfate with the later-formed coating of insoluble lead carbonate tends to armor the galena and prevent further solution. Abundant evidence of the insolubility of galena is observable throughout the district, as most of the lead mined was found in the zone of oxidation and was coated with the carbonate and sulfate. Likewise, these armored galena masses are even more resistant to solution than many of the carbonate rocks themselves, as is shown by the large residual and occasional placer lead deposits. Some lead of course, descends in solution, but most of it tends to remain; thus it parts company with the zinc, iron, and copper.

If iron, lead, zinc, and copper are assumed to have dissolved in the meteoric waters in the zone of oxidation, an adequate mechanism for their precipitation as sulfides at greater depths must be found by the supporters of the meteoric hypothesis. In downward sulfide enrichment of ore bodies, the reducing action of primary sulfides below the zone of oxidation is the principal mechanism that causes precipitation. In the decending water hypothesis the claim is that only the primary minute disseminations of sulfides would exist, and the quantities in any area of rock the size of a pitch-and-flat deposit would be totally inadequate to produce the necessary reducing action for this type of precipitation. The followers of the artesian theory claim slightly larger original concentrations, which however are still probably insufficient to have any major reducing effect.

The lead-zinc-copper minerals in the primary ores below the water table are not those normally expected by secondary enrichment. For example, iron in secondary enrichment deposits combines with an element such as copper to form bornite. Lead and zinc are redeposited as carbonates by the replacement of the limestone, but only uncommonly as galena and sphalerite and wurtzite. Likewise, secondary copper sulfides are generally chalcocite, bornite, and covellite, but only rarely chalcopyrite. Therefore, no close analogy exists between the deposits of the upper Mississippi Valley type and the typical deposits of secondary sulfides elsewhere produced by downward enrichment.

Although organic matter in the form of the carbonaceous shales of the Guttenberg limestone member has been also referred to as the reducing and precipitating agency, the association might be fortuitous, rather than genetic. In the district the most highly carbonaceous layer is the Guttenberg member, especially where altered to shaly oil rock, and yet this member definitely contains less ore in most deposits than the less carbonaceous beds above and below. The rich lead deposits of the mineralized joints are principally in the Galena dolomite as much as 200 feet above this member, and large lead and zinc ore bodies are in the McGregor limestone member that lacks carbonaceous shales, as much as 35 feet below the Guttenberg. Possibly precipitation from the meteoric waters could have been delayed until after they had passed through the carbonaceous beds of the Guttenberg and Quimbys Mill in their descending course. Experimental evidence presented by Bastin (1926, p. 1281–1286) seems to be preponderantly against the theory that organic matter is capable of reducing sulfates at ordinary temperatures.

The appeal to hydrogen sulfide and other easily soluble sulfides as the precipitating agents does not appear well-founded in this district. It is true that hydrogen sulfide does occur locally in some quantities in beds of Cambrian age of the area, but it was noted in the ore-bearing strata only at one place, the Trego mine near the mine water level, where sulfides were being oxidized by ground waters. The supporters of the meteoric hypothesis have to explain why hydrogen sulfide is not of common occurrence in the ore-bearing beds at the present time, especially because they claim deposition of sulfides in the ore deposits is very probably still taking place.

Possibly one of the strongest arguments that has been advanced by advocates of the meteoric hypothesis is the apparent restriction of the principal ore deposits to shallow depths and their supposed conformable relation to the old peneplain surface rather than to certain stratigraphic horizons. It is now known, however, that the ore bodies are located in favorable stratigraphic horizons and fractures in all the rocks instead of at equal distances below the old peneplain level. Deposits of galena, pyrite, marcasite, sphalerite, and chalcopyrite are known in all the rocks of the district down to the Franconia sandstone of Cambrian age, far below the main ore-bearing Platteville, Decorah, and Galena strata. Considerable quantities of sulfides have been found in the Prairie du Chien group along the north edge of the main district where the Galena-Decorah-Platteville beds have been progressively eroded away. Drilling by the Geological Survey (Heyl, Lyons, Agnew, 1951) showed zinc and iron sulfides in the Prairie du Chien at several places within the main district, and these occurrences of sulfides suggest that mineable ore deposits may be locally present in this group.

Under this meteoric hypothesis, the impervious, shaly, incompetent layers near the Platteville-Decorah boundary were supposed to prevent any passage of the ore-bearing solutions through these beds. However, the numerous fractures that cut through these beds and especially the large bodies of ore in the Platteville formation refute this older idea. The Platteville formation was formerly considered barren by many geologists and miners except along the north edge of the district, but deposits developed since 1940 show it to be nearly as good a host rock as the Galena dolomite practically everywhere in the producing district.

The meteoric hypothesis explains with difficulty the regular order of deposition of the ores in the district. This regular sequence of deposition was well known and described by geologists as early as 1862, although the details were not worked out (Whitney, 1862, p. 243). This regular mineral sequence is uniform throughout the district. The meteoric hypothesis assumes that the ores have been deposited in minute quantities over tremendous periods of time. Many known mineral deposits from meteoric waters consist of innumerable layers that are successive crusts of minerals, such as limonite, bauxite, and pyrolusite ore bodies and many secondary sulfide-enrichment deposits. The only apparent alternative would be that, over the tremendous period of time of deposition, first one metal, then a second, and so on was dissolved, carried down and redeposited in a regular order, while the others remained unattacked or at least unprecipitated. A regular sequence of deposition is not as probable by meteoric agencies, although it is typical of many known magmatic ore deposits.

THE MAGMATIC HYPOTHESIS

Areas of similar deposits.—The deposits of this district are similar lithologically, mineralogically, and, to a certain extent, structurally (and therefore probably in origin) to other well known districts of the Mississippi Valley, such as the Tri-State lead-zinc district of Missouri-Kansas-Oklahoma, and the lead-zinc deposits of northern Arkansas. Likewise, notably close similarities such as banded veins and solution thinning (Grogan, 1949) are abundant in the bedded replacement flourite-zinc-lead deposits of southern Illinois. Less similar are the lead deposits of southeastern Missouri, the barite deposits of east-central Missouri, and the filled-sink iron deposits of central Missouri. Farther afield, deposits commonly included in the "Mississippi Valley type," (Bastin and others, 1939) are those in the limestones of Paleozoic age of the eastern United States at Friedensville, Pa., and southeastward at Austinville, Va., and Mascot, Tenn. Deposits of essentially the same nature occur in many parts of western Europe, and similar deposits are in the Leadville, Colo. (Loughlin and Behre, 1934, p. 215–254), Metalline Falls, Wash., Duck Creek, Nev., and in the North Tintic, and Promontory, Utah, districts.

In all these districts the country rock is limestone and dolomite. Shaly layers commonly underlie or overlie the ore. The rocks in many of these districts are neither greatly deformed nor metamorphosed. Where igneous rocks are present, they have not been definitely related to the ore deposits.

The primary mineralogy of such ores is relatively simple, and generally the most common minerals are sphalerite, wurtzite, galena, pyrite, marcasite, barite, flourite, cryptocrystalline quartz, calcite and chalcopyrite. In most of these districts except those in the western United States the same two general conflicting theories of origin (meteoric and magmatic) have been applied and long discussed.

The source of the metals.—Of all the factors involved in a magmatic hypothesis for the Upper Mississippi Valley deposits, perhaps the one for which the least tangible evidence exists is the original source of the metals. All the known igneous areas in the vicinity are of Precambrian age, and so cannot be considered as a source of the mineralizing solutions, which are much later in age. The nearest occurrences of igneous rocks of post Precambrian age are very small intrusives, most commonly of mafic rocks, in central and eastern Missouri and in the Illinois-Kentucky fluorspar-zinc district (Bastin and others, 1939, p. 71–100). Three small areas of highly disturbed rocks in northeastern Illinois and eastern Wisconsin are possibly cryptovolcanic structures, but the evidence of their igneous origin is meager at best, and in none of these structures have any igneous rocks been discovered. These facts, coupled with the earlier geologists' general lack of recognition of igneous magmas as sources of ore deposits, caused many to embrace the meteoric hypothesis of ore formation.

Elsewhere in the Mississippi Valley numerous small and widely scattered intrusions of igneous rock known to be as late as mid-Cretaceous in age suggest the possibility that Paleozoic or Mesozoic intrusions may exist at depth in this region. Such magmatic bodies, if present, probably never rose as far as the surface of the Precambrian basement, but lie within it and would therefore be most difficult to date with any precision. The low temperatures of deposition of these ores suggested by Newhouse (1933, p. 748) and Bailey and Cameron (1951) would indicate that the deposits are far from a magmatic source.

It is much less difficult to postulate derivation of the ore deposits from a magma a few thousand feet beneath the district than by some of the complex systems suggested by supporters of the meteoric hypothesis. The proposed hypothetical ocean currents and "Sargasso sea" of Chamberlin (1882, p. 529–549), or the artesian circulation in which the ore-bearing solutions are supposed to have traveled hundreds of miles laterally through the sediments, suggested by Van Hise (Van Hise and Bain, 1902, p. 411–426), are unnecessarily difficult modes of transportation over great distances, and little factual data for their existence are known. The same men, who are quite willing to suggest that the solutions traveled the hundreds of miles laterally through the strata, did not consider possible the rise of solutions only a few thousand feet vertically, even though rising magmatic solutions offer a simple explanation that has been proved in many other lead and zinc deposits.

The widespread faults and joints are now known to provide a connected fracture system between permeable beds that could have provided the needed access for the rising solutions. At least in a few places in the district, faults are present of such large displacement that they very likely continue into the Precambrian basement. The exposed sedimentary rocks of all ages are transected by a complex fracture system of minor faults, the individual fractures of which do not have any great vertical extent, but connect with others and also with bedding-plane faults of considerable lateral extent, as well as with aquifers such as the St. Peter sandstone and the sandstones of Cambrian age. Water movements through the system are thus relatively unimpeded both vertically and laterally. It should be noted that very similar evidence was presented by Percival

(1855, p. 68). Many geologists later misinterpreted his statements to mean that the smaller fractures continued without break to the basement.

The numerous fractures and faults cut across the supposedly impervious shaly layers at the Platteville-Decorah boundary. Large ore bodies above and below these "impervious" layers, show that, although these layers may have locally impeded the solution movements, they did not prevent the passage of solutions through them. The shaly beds in pre-Decorah formations, commonly less thick, are cut by similar faults and fractures in many places. Thus the belief that these thin shaly horizons form impervious layers which prevented vertical movements of underground waters is not substantiated. Although undoubtedly the Maquoketa shale above is nearly impervious in places, it is much thicker.

Evidences of rising solutions may be noted in the regional stratigraphic arrangement of the ore bodies and also within the ore bodies themselves. Most of the known large ore bodies are in the Galena, Decorah, and Platteville formations. Ore is concentrated beneath the Spechts Ferry shale member in the Quimbys Mill member at the top of the Platteville formation. The shaly layers of the Spechts Ferry may have impeded somewhat the upward flow of the ore-bearing solutions and caused them to spread out beneath the shale, but many transecting fractures provided passage of the solutions through these layers. The shaly layers of the Spechts Ferry contain small ore concentrations near many such fractures, but the more competent beds above, like the Ion dolomite member, are full of fractures and cavities and contain large deposits of ore. Only a little ore has been found in the Maquoketa shale and in the dolomites of Silurian age. Lead deposits formed from damming and spreading out of solutions in the topmost beds of the Galena dolomite just beneath the Maquoketa shale have been noted by geologists (DeWitt, O. E., 1947, Stoops, C. W., 1949, written communications). Where ore is found in the Maquoketa shale it is, for the most part, only in the basal beds; small quantities of the ore minerals are quite common over large areas in these basal beds, which also suggests that rising ore solutions were dammed and spread out beneath this thick impervious formation.

Within the ore deposits themselves similar evidences of rising solutions are common. In the gash-vein deposits the ore is in the openings along joints, commonly just below a thick, less pervious, massive dolomite layer known locally as the "cap rock" which apparently impeded the upward flow of the solutions. A vertical joint cuts this "cap rock" in most places, but it is commonly a relatively tight fracture. A similar relation is seen in the pitch-and-flat zinc bodies. Most such ore bodies have the shape of inverted saucers or upward pointing wedges and are restricted to the foot wall sides of the main inclined fault zones which enclose them. Apparently the gouge-filled fractures that delimit the hanging wall sides of the ore bodies impeded or prevented the upward and outward flow of the ore solutions. Even where parallel fractures lie outside of the main pitch zones in the hanging wall and roof areas, they are generally unmineralized, or only a little mineralized. In contrast much of the relatively unfractured rock which is common in the central foot wall area between the opposing inclined shear zones (pl. 20) contains abundant sulfide deposits. This evidence is corroborated by the stalactitic forms which are in the ore bodies themselves. In all of the places where these sulfide stalactitic forms were noted by the writers, they grew upward into the cavities and not downward as expected (fig. 56). As in most places these stalactitic forms were seen in flats, this relation is quite definite. Some of the stalactitic forms have central tubes an inch in diameter, that further suggest an origin by upward-flowing jets of ore depositing solutions.

The many other elements, besides the lead, zinc, iron, and sulfur associated with the ore, add serious complications that are difficult to explain by the meteoric hypothesis. It is improbable that conditions of meteoric concentration and deposition were ever so ideal as to precipitate and concentrate all these elements in one limited area. The cobalt, arsenic, silver, gold, and molybdenum appear significant, as they very rarely are found elsewhere than in known hydrothermal deposits.

Graton and Harcourt (1935, p. 800–824) have made roughly quantitative X-ray and spectroscopic analyses of the small amounts of metals other than zinc in sphalerite from ores of other districts in the Mississippi Valley, and from ores of accepted magmatic associations.[32] They concluded that Mississippi Valley type ores are similar enough to those of generally accepted magmatic affiliation to suggest a similar genesis. The quantities of the elements Cd, Ga, Ge, and In are particularly close. As the sphalerite of this district is known to contain equivalent amounts of three of these four significant elements and the fourth, Ga, was not determined, their conclusions can be applied specifically to the district.

A regional tectonic deformation apparently began sometime before the depositon of the ores (fig. 58); it continued with diminishing intensity during the deposition of the ores, and ceased at the end of the ore deposition or probably shortly thereafter. This sequence of

[32] Similar determinations by spectroscopic analysis of sphalerite concentrate from this district have been made by the U. S. Geological Survey showing that the elements Bi, Cd, Sb, Sn, and Ge at least, are found in equivalent amounts in this district.

deformation produced the joints, major and minor folds, bedding-plane and reverse faults, shear faults, and some of the brecciation of the ores at several times during their deposition, most probably in the order just given. The influx of hydrothermal solutions and the deposition of ores toward the end of a period of deformation is quite characteristic of ore deposits of proven hydrothermal origin.

Applying the hypothesis that these deposits are of hydrothermal origin derived from a remote magmatic source somewhere within the underlying Precambrian basement rocks, the question arises as to the age of the deposits. This question cannot be answered definitely from any of the known relations in the Mississippi Valley. The rocks of the district were all gently warped during the main regional tectonic deformation, which was at least post-Middle Silurian in age, and, to judge from nearby regional relations, probably Pennsylvanian or later. The known intrusions elsewhere in the Mississippi Valley are quite remote from the district, and most of their age relations are not especially clear. In the Illinois-Kentucky fluorspar district the mafic intrusions are known to be of Cretaceous age, for they cut the lower Cretaceous rocks but not those of Late Cretaceous age (Bastin and others, 1939, p. 131). The age of these intrusives is in general agreement with the known age relationships of other such intrusions elsewhere in the Mississippi Valley. As the deformation that produced the LaSalle anticline extension of the Wisconsin arch continued at least to the close of the Pennsylvanian, the best probable inference that can be made in regard to the age of ore deposition is that it occurred sometime between late Paleozoic time and the end of the Mesozoic. Lead ore has been found in the glacial gravels of Clinton County, Iowa, and so the deposits were in existence before the Pleistocene epoch.

Compositon of the mineralizing solutions.—The composition of underground waters now filling the cavities and fractures has no genetic significance in the magmatic hypothesis of origin, unless it can be shown that waters of this composition were present also at the time of ore deposition and the hydrothermal solutions, mingled with them. Probably, if the ores are derived from hydrothermal solutions, existing meteoric waters, and possibly even connate brines, intermixed with the rising solutions, modifying and diluting them to a certain extent, and probably also lowering their temperature. Mingling of the hydrothermal and meteoric solutions and the resulting changes in composition may have been one of the important factors in precipitation of the primary ore minerals.

In order to determine the composition of the solutions that deposited the ores of this district, Newhouse (1932, p. 419–435) made qualitative tests of the liquids of original fluid inclusions and negative crystal cavities in galena and sphalerite from the district, as well as from the Tri-State and the southeastern Missouri districts. The elements in these solutions are sodium, calcium, and chlorine; the sodium greatly predominates over the calcium. Rough quantitative tests by Newhouse indicated concentrations of 12 to 25 grains of NaCl per 100 cc. of water, as compared to an average of 3.5 grains in ordinary sea water. He found similar brines in fluid inclusions from Leadville, Colo., Freiberg, Saxony, and Santander, Spain; and in all these places the ores of lead and zinc are abundantly associated with volcanic rocks and considered to be of hydrothermal origin. His results show that the solutions at the time of ore deposition in the known magmatic deposits were very similar to those in inclusions from Wisconsin. Such high chloride concentrations appear to be irreconcilable with any hypothesis that postulates meteoric waters as the main agent of ore deposition. These results are, however, in accordance with the magmatic hypothesis, as waters of similar quality, though of less concentration, are characteristic of certain hot springs within areas of ore deposition. The extraordinary abundance of the chloride radicle in the emanations of many volcanoes is well known (Fenner, 1933, p. 58–106), and chlorine and sodium are both important magmatic constituents.

Although the composition of the fluid inclusions suggests a magmatic source, they could have originated in connate brines in the sandstones of Cambrian age, or at least in a mixture of connate waters and magmatic waters. Connate brines are not known within the main district itself, but have been found in a four-foot layer of sandstone of Cambrian age at a depth of 510 feet at Prairie du Chien, Wis. Waters from similar strata at McGregor, Iowa, across the Mississippi River, are also slightly saline (Strong, 1882, p. 61–62). Although this occurrence is very local, saline waters, perhaps of connate origin, may have been much more widely distributed in the sandstones of Cambrian age at one time. Similar connate waters elsewhere have a NaCl content much less concentrated than the fluid inclusions in galena in Wisconsin. The brines of the inclusions are too concentrated to be from the known connate waters or a mixture of magmatic and connate waters, later diluted by meteoric waters.

The transport of lead, zinc, iron, and copper in igneous solutions in balance with the chloride radicle involves no chemical difficulties (Bastin and others, 1939, p. 133). Zinc, iron, and copper chlorides are highly soluble even at ordinary temperatures. Lead chloride has a lower solubility, which, however, is increased at higher temperatures and in the presence of HCl.

Temperature of ore deposition.—Certain minerals in hydrothermal ore deposits are considered indicative of the general temperature conditions of the ore deposition. The lead and zinc deposits of this district contain no known high-temperature minerals, nor have the wall rocks been replaced or changed, other than to sericite at one locality by alterations, indicative of fairly high temperatures. Many lead and zinc deposits are thought to have been deposited at relatively low temperatures. These facts suggest that the deposits of this district, if of hydrothermal origin, were precipitated from relatively low temperature solutions.

Marcasite, which is a common constituent of the ores, is known to have formed from both meteoric and hydrothermal solutions. Where it is found in hydrothermal ore bodies, marcasite was generally deposited in the closing stages of mineralization, indicating its formation under low temperatures. The common occurrence of marcasite in the district would therefore imply moderate to low temperatures of mineralization.

The ores contain small quantities of a number of elements which are significant in respect to origin. These elements include nickel, potassium, cobalt, arsenic, gold, silver, germanium, copper, vanadium, molybdenum, and barium. Some of these, such as gold, silver, vanadium, cobalt, arsenic, and molybdenum, are in very small quantities, detectable only by analysis. Others such as nickel, barium, and copper are found locally in considerable quantities with the ores. The nickel is in the form of millerite, a form which in other districts is of low-temperature hydrothermal origin, or occasionally probably of meteoric origin; however, it occurs in Wisconsin with the other primary sulfides.

Newhouse (1933, p. 744–750) approached the temperature problem by studies of fluid inclusions in sphalerite. He heated chips and sections of selected primary sphalerite crystals, and examined them under the microscope, and then noted the temperature at which the gas bubbles in the liquid inclusions disappeared. With increase in temperature, the internal pressure of the liquid portion of the inclusion increases, and its capacity for dissolving gases also increases. When a certain temperature is reached, all the gas bubbles in a given specimen disappear. Assuming that at the time the ores were deposited only the liquid phase existed, the temperature of disappearance of the bubbles represents the minimum temperature at which deposition could have taken place. Newhouse thought that this minimum was close to the actual temperature of ore formation. He examined samples from two localities in the upper Mississippi Valley district, which gave the following results (Newhouse, 1933, p. 748):

Locality	*Remarks*	*Temperature (° C)*
Badger mine, Hazel Green, Wisconsin.	Dark brown, massive sphalerite intermixed with pyrite and marcasite.	80–100
Wisconsin	Banded ore, mainly dark brown sphalerite, minor galena.	90–105

From these determinations he concluded that the temperature of formation of the ores of this district was from 80° to 105° C.

Since 1948 additional, more-comprehensive, temperature studies of the non-opaque minerals of the ores of this district have been in progress at the University of Wisconsin. The Newhouse liquid inclusion method has been used. Cameron and Bailey [33] have kindly supplied a summary of the preliminary results:

To date, results of detailed studies of liquid inclusions in sphalerite and calcite from 8 mines in the Wisconsin-Illinois lead-zinc districts are as follows:

1. Bubbles in liquid inclusions in sphalerite disappear at temperatures ranging from 75 degrees to 121 degrees centigrade.[33a] Most of the bubbles disappear at temperatures between 75 degrees and 100 degrees centigrade. In specimens from two of the three mines most extensively sampled, there is no evidence of systematic variation in temperature during sphalerite deposition. Most specimens from the third mine, however, suggest an orderly variation in temperature. Temperatures of disappearance range from a maximum of 93 degrees centigrade for the earliest-formed vein sphalerite to a minimum of 75 degrees centigrade for the latest-formed vein sphalerite. No indication of systematic variation in temperatures of deposition from place to place within a given ore body have been found in samples from any of the three mines.
2. Bubbles in liquid inclusions in calcite crystals of types 2 and 3 disappear at temperatures of 50 degrees to 77 degrees centigrade. Many crystals studied proved unusable owing to leakage of inclusions upon heating, but the data at hand appear adequate to indicate the general range of temperatures of disappearance for calcites of the types named. No data for calcite of types 1 and 4 have yet been obtained.

A report on their results is now published (Bailey and Cameron, 1951). The orderly regular decrease in the deposition temperatures of sphalerite indicated by the studies of the specimens from the "third" (Liberty) mine, as well as the much lower temperatures of deposition of the calcite (commonly the latest mineral of the ore deposits) conform to relations expected if the ores

[33] Cameron, E. N., and Bailey, S. W., 1950, written communication.
[33a] A correction of between plus 10 degrees and plus 20 degrees centigrade needs to be applied to the data given above to allow for pressure. All values would be raised by the same amount, hence relative values remain unchanged.

are hydrothermal. As it is postulated that from this district not more than 1,000 to 1,500 feet of sediments have been eroded, the temperatures are higher than would be expected with a normal geothermal gradient, even if the ores were deposited when all these sediments were present.

Zoning of the ores and mineral sequence.—One of the marked features of the district is the vertical and horizontal zoning. Much of this zoning is difficult to explain except by a hypothesis of hydrothermal origin because the ores were deposited in an unbroken cycle. The definite concentration of most of the barite, copper, nickel, cobalt, and gold in northwest-trending zones passing through the east center of the district is notable. This type of areal zoning is a common feature of hydrothermal districts such as Butte, Mont., and Tintic, Utah and is hardly explainable by the meteoric hypothesis. The horizontal zones in the district do not seem to follow the more important regional structures or even the centers of mineralization, but transgress them. Minerals of the elements listed above are deposited in the latter part of the paragenetic sequence, and occur in much greater abundance in these northwestward zones than elsewhere in the district, even though their paragenetic relations and occurrence in small quantities outside the zone indicate that they do not represent a separate, later mineralization, but are all part of the same general period of ore deposition. The horizontal zones probably have a direct relation to the source of the ores, and may possibly indicate the location of the source intrusion.

Besides the regional zoning, a vertical zoning is present in the district. Some of the vertical zoning, such as the preponderance of iron sulfides in the St. Peter sandstone, is probably caused by a difference in chemical affinities of the host rock. But other zoning, such as the abundance of silicified and dolomitized wall rocks in deposits in the Prairie du Chien group beneath the main pitch-and-flat ore bodies, is probably caused by differences in composition, higher temperatures, and greater pressures of the depositing solutions in these deeper strata than in the deposits above.

The paragenetic sequence of the ores throughout the district shows a single cycle of deposition, and only local variations in relative quantities of the minerals. Within the time range of a certain mineral in the cycle, one or two repetitions of deposition of the mineral may occur, but not repetition of any considerable part of the sequence was observed anywhere. The same regular, unvarying order of deposition of the primary ore minerals is in every ore body: quartz, dolomite, pyrite, marcasite, sphalerite, galena, barite, chalcopyrite-millerite, and calcite (4 habits in a regular sequence).[34] These facts are very difficult to explain by a meteoric theory of genesis, for, if the ores originated through the progressive weathering of sedimentary formations over great periods of time, and if they were deposited in innumerable small precipitations, then there should be many repetitions of the sequence, and a complex banding such as is common in cave travertine, limonite deposits, and many secondary sulfide enrichments in sulfide ore bodies.

Forces motivating circulation.—Under the magmatic hypothesis, pressures that originated in the parent magma must be regarded as supplying the initial impulse that propelled the mineralizing solutions outward and upward. As the solutions approached the land surface, they would probably continue to rise through the pre-existing zone of meteoric and possibly connate waters because of their higher temperatures. The apparent relatively low temperature relations of the deposited minerals themselves indicate that they traveled far from their source.

Sandstone aquifers such as the St. Peter sandstone and the sandstones of Cambrium age that alternate with successive relatively permeable and impermeable calcareous and shaly beds may have aided notable lateral movements of the solutions, and spread them over the large area of the district. The known fracture systems would aid this type of movement, and groups of fractures in local zones of more intense deformation would tend to localize the hydrothermal solutions into centers of concentration. As previously suggested, considerable mingling and dilution by meteoric waters probably occurred. The thick, relatively impermeable Maquoketa shale cap that formerly covered most of the district very probably hindered further upward circulation of the solutions, and caused them to spread laterally through the underlying limestone, sandstone, and dolomite beds.

Stratigraphic distribution and relations of the ores.—Many geologists have assumed that the ore deposits are essentially limited to the Galena dolomite and Decorah formation, and that the supposed impervious shaly layers at the base of the Decorah prevented any passage of either ascending or descending solutions. The fallacy of this "impervious layer" as well as the existence in the district of numerous important ore bodies in the supposedly barren Platteville formation has already been pointed out. Likewise, as previously sug-

[34] This order of deposition is the same as the sequence of main primary minerals in the vertical zoning, that is (1) quartz and dolomite in the Prairie du Chien group, (2) pyrite and marcasite in the St. Peter sandstone, (3) sphalerite in the Platteville and Decorah formations, and (4) galena and chalcopyrite in the Galena dolomite (Dutton, C. E., 1952, personal communication).

gested in the discussion of the meteoric hypothesis, the sparsity of known sulfide deposition in dolomite of the Prairie du Chien where it is exposed along the north fringe of the district is not sufficient evidence that mineralization did not occur in these beds within the main district. The discovery of considerable quantities of zinc and iron sulfides in several Geological Survey drill holes put down into the Prairie du Chien at widely spaced localities within the main district, suggests that this group may be an important ore-bearing unit. The chance of these few drill holes locating large ore deposits is remote. In the only hole that penetrated a considerable thickness of strata of Cambrian age, zinc and iron sulfides were also present, indicating that sulfide deposits may exist in all the deeper Paleozoic beds within the main district.

Known lead and zinc deposits are sparse in both the St. Peter sandstone and sandstones of Cambrian age. The Cambrian, however, contains large pyrite concentrations in the north fringe of the district, and the St. Peter has considerable deposits of iron sulfides in the main district. The sparsity of lead and zinc and the abundance of iron sulfides may be related to the nature of the solutions, their precipitating agents, vertical zoning, composition, and great permeability of the sandstones rather than to a lack of passage of lead- and zinc-bearing solutions through these strata.

Chemistry of probable ore solutions and of precipitation of ore minerals.—In order to transport the metals and deposit them in the beds where they are now, a solvent must have been present in which the lead, zinc, and iron were about equally soluble, and which held these metals in solution until temperatures dropped to around 100 degrees centigrade. Perhaps the most pertinent discussion of this question was given by Slobod (Bastin and others, 1939, p. 140); because of its importance, his discussion will be presented in full:

A critical question in the chemistry of precipitation of lead and zinc sulfides from rising solutions comes from the fact that primary lead sulfides generally occur nearer the surface or farther from igneous rocks than zinc sulfides. The relative solubilities of the zinc and lead salts themselves, though carefully considered in connection with these studies, do not seem to offer an adequate explanation for this distribution. A possible explanation may be founded upon the following chemical considerations.

The solubility of lead sulfide, which depends upon temperature, hydrogen ion concentration, and pressure is also a function of the neutral chloride ion concentration (Dede and Bonin, 1922, p. 2327), whereas the solubility of ZnS depends mainly upon temperature, pressure, and hydrogen ion concentration, but not on neutral chloride ion concentration.

Although ZnS is ordinarily considered soluble in acid, it is pertinent to observe that in a solution as highly acid as 0.25N, only 0.058 moles of ZnS are soluble in 1 liter of the solution at 18° C. Of course, under the same conditions, only about 1.66×10^{-6} moles of PbS are soluble, but if neutral chloride (as $CaCl_2$ or KCl) is added the solubility of lead is greatly increased. What counts here is the concentration of chloride as against hydrogen ion. The magnitude of the neutral chloride effect can best be gauged by the following data:

In the work referred to above, solutions (100 cc. containing 20.7 mg. of Pb), containing various concentrations of $CaCl_2$, were saturated with H_2S at various temperatures and at various acid concentrations. The important results may be summarized as follows:

At room temperature, 1.4N, HCl is required to prevent precipitation when no $CaCl_2$ is present, while only .2N acid is required to prevent precipitation, when the solution is 2.8N in respect to the neutral chloride ion.

At higher temperatures, the effect of the neutral chloride is aggravated since 1.2N $CaCl_2$ requires about 0.95N, HCl at 0° C. to prevent precipitation, while at 100° C. only 0.1N is required.

The effect of pressure has not yet been considered. No laboratory evidence is available, but increased pressure should act to increase the precipitation of ZnS, since the lead is protected and is held in solution in the form of a complex salt, such as $PbCl_4^{=}$ or $PbCl_6^{-}$ (Dede and Bonin, 1922).

When the factor of high pressure, in addition to temperature and neutral chloride ion concentration, is considered, it is seen that there is a trend toward the inversion of lead and zinc sulfide precipitation, such as is actually encountered in nature (Moses and Behr, 1924, p. 49–74; Feigl, 1924, p. 25–46).

In the sulfides of the upper Mississippi Valley district, the work of Newhouse (1932, p. 419–436) has shown that the dominant ions in the crystal inclusions, presumably remnants of the mineralizing solutions, were Ca^{++}, Na^{+}, and Cl^{-}. In view of this information and the chemical data just cited, the solutions may be assumed to have been rich in the ingredients normally present in hot springs and volcanic emanations. To assign these solutions to descending waters leaves noteworthy quantities of Na^{+} and Cl^{-} to be explained; to assign them to laterally moving artesian waters raises questions as to the source of the S^{-} (in oxidized form), and how these elements became so concentrated in the solutions. Hydrothermal solutions derived from a magmatic source seem to satisfy all the necessary requirements.

Causes of precipitation.—The important factors of precipitation may have been (as in other hydrothermal deposits) declining temperature and pressure, assuming that the mineralizing solutions were hydrothermal and the ore deposited during a single period.

The composition of the ores and their fluid inclusions, and the known composition of waters from thermal springs in active volcanic regions and from the volcanoes themselves, suggest that the mineralizing solutions, if derived from a magma, carried water, silica, and the metals, plus the base radicles Na, K, Ca, and Mg, and the acid radicles S, Cl, CO_2, and H_2CO_3 together with other minor components. Probably also these solutions were acid when they issued from the magma, but were neutralized by limestones and dolomites and by mixing with neutral or slightly basic meteoric waters typical of carbonate rocks. The Platteville and Decorah formations that contain the main pitch-and-flat deposits contain the first limestone strata above the pre-Cambrian.

Behre (1933, p. 192) suggested how such neutralization would effect sulfide precipitation from rising acid solutions. He stated that it is well known in analytical chemistry that hydrogen sulfide in acid solutions will precipitate copper and lead, but not zinc. If the acidity is neutralized, the H_2S becomes more effective and precipitates zinc and iron. The ore-bearing solutions were probably complex, and such precipitation would have been influenced by other factors, so that the net effect is not readily predictable. Nevertheless, the neutralization of the solutions may partly explain the sudden change in the proportions of lead and zinc in the usual 100 feet of vertical distance between the gash-vein lead deposits and the pitch-and-flat zinc deposits beneath.

Abundant evidence in the district indicates that considerable interaction took place between the ore-bearing solutions and the wall rocks with which they came in contact. Metasomatism on a large scale is recorded in the silica and dolomite which replaced the limestone and dolomite host rocks, and in the solution residues. Abundant magnesium and calcium carbonate were probably added to the solutions during the alteration of the carbonate rocks. This addition of magnesium and calcium to the solutions is evident in the dolomitization that occurred during the early stages of mineralization, the great quantities of limestone dissolved by the ore-bearing solutions, and the abundant calcite deposited in the last stages of ore deposition. How much effect this reaction with the limestone wall rock would have on the solutions is not known, but it would certainly lower the acidity, or neutralize originally acid solutions.

There is a very definite possibility that solutions mingled with meteoric water and also some possibility that they mingled with saline connate waters. This co-mingling probably would tend to depress the temperature gradient of the thermal waters and thus facilitate ore deposition. An additional possibility is that meteoric waters would tend both to dilute and, to a certain extent, to neutralize rising acid solutions. Meteoric waters in areas of calcareous rocks generally are neutral or slightly basic, and contain large quantities of dissolved calcium and magnesium bicarbonates.

The presence of hydrocarbons in the oil shales of the Platteville and Decorah formations also may have aided the precipitation of the sulfides. However, the field evidence is somewhat to the contrary, as the oil rock, which contains most of these hydrocarbons, is a relatively poor host rock compared with the less carbonaceous beds below it and the only sparsely carbonaceous, dolomitic beds above it.

Objections to the magmatic hypothesis.—Certain serious objections to the magmatic hypothesis can be pointed out by supporters of the meteoric hypothesis.

1. The suggested source of the ores is purely theoretical, for this hypothesis proposes the existence of an igneous magma at depth in the Precambrian basement rocks of the district; no direct evidence of this magma is known and the evidence for its existence is derived from the geology and nature of the deposits themselves. This source is, therefore, just as hypothetical as the sources proposed by supporters of the meteoric theory.

2. The ore bodies consist entirely of minerals known to be, or capable of being, deposited by meteoric waters. The only exceptions are the small quantities of unusual elements present in the ores, the sericite in the silicified wall rocks of the Demby-West deposit near Dodgeville, Wis., and the silver in the chalcopyrite at Gratiot.

3. The known ores are mostly concentrated in the Platteville, Decorah, and Galena strata and near the present surface; if many large ore deposits exist in the Prairie du Chien strata beneath the main district, they have not yet been found, although available evidence suggests they may be present. This concentration of known ore in the formations near the present land surface is readily explainable by the meteoric hypothesis. The hypothetical immediate source of the metals would be the beds surrounding or immediately above the present concentrations.

4. The minute concentrations of the metals present in the "source" beds today, if they were all freed and gathered together in ore bodies, would equal in quantity all the known deposits of ore in the district. Very probably large quantities of these metals have been redissolved and transported by meteoric waters in the tremendous period of time since deposition of the rocks. It is evident that the wall rocks of the deposits were dissolved in large quantities during ore deposition, probably adding lead and zinc to the depositing solutions.

5. In former geologic times saline connate waters might have existed and contained sufficient hydrogen sulfide to deposit lead and zinc ore from artesian solutions.

CONCLUSIONS

The authors believe that the balance of evidence is on the side of the magmatic hypothesis, which postulates the deposition of the ores by hydrothermal solutions, although this theory cannot be considered as absolutely proved. Even though the work was undertaken with the views of Grant, Chamberlin and Van Hise in mind, practically all of the evidence obtained during the course of the work, favors the genesis of the ores by deposition from rising thermal waters. The notable similarity between ore bodies and veins of this district, and those of proven hydrothermal districts is apparent. However, the question cannot be considered closed, and the writers are well aware of the limitations of the evidence presented. A great deal more knowledge of the mineralogy, temperatures, and other physical and chemical factors controlling ore deposition, and of the geology of the hitherto-unexplored rocks beneath the known part of the geologic formations, would be necessary before these ore deposits could be proved beyond doubt to be of hydrothermal origin.

SECONDARY CHANGES IN THE ORE DEPOSITS

The primary lead, zinc, iron, and copper sulfide deposits of the district are leached and oxidized where they are within 30 to 100 feet of the present land surface. The oxidation of the ore minerals is complete in many places, except the galena, which remains mostly unoxidized and only is coated with lead carbonate. Incised streams have lowered the water table from 30 to 100 feet in many places, and thus have exposed primary ore deposits between valleys to supergene changes by downward-moving vadose waters. In places where stream valleys overlie primary deposits, the ores are not altered by supergene changes owing to protection afforded the underlying sulfide deposits by maintenance of the water table at the surface and the neutral waters in the carbonate rocks beneath. The oxidized zone generally continues for a few feet below water table, and, in a few places, extends along open fractures to a depth of 100 feet below the surface of the water table. Secondary sulfides are common only in the few copper deposits, and are found at or just below water table. No secondary lead and zinc sulfides are known.

As in many other districts, this general area of supergene minerals can be divided into three parts, in descending order: the zone of leaching and oxidation, the zone of enrichment containing secondary oxidized ores, and the zone of secondary sulfide ore enrichment. Table 8 shows the main primary minerals of the ores, the elements they contain, and the supergene minerals produced from them.

ZONE OF LEACHING AND OXIDATION

Beds that contain the primary sulfide deposits in the district have been eroded in many places, and some ore bodies have been almost completely removed by erosion. Such erosion, accompanied by oxidation and leaching, is particularly common in gash-vein deposits, and also in many pitch-and-flat deposits especially in the northern part of the district where the regional rise of the beds expose Galena, Decorah, and Platteville strata at the surface over much of the area. Sphalerite and marcasite deposits are leached and oxidized. The zinc sulfide has been oxidized to zinc carbonate (smithsonite), and less commonly to hydrozincite, hemimorphite, sauconite, and goslarite. Because oxygenated water acts much more slowly on sphalerite than on associated iron sulphides, oxidation is most probably accomplished by sulfuric acid developed from the de-

TABLE 8.—*Minerals formed by oxidation and redeposition*

Primary minerals	Principal elements present in minerals	Resulting secondary minerals						
		Elements	Sulfides	Oxides	Arsenates phosphates	Silicates	Carbonates	Sulfates
Galena	Pb, S, also Ag	Sulfur			Pyromorphite		Cerussite	Anglesite(?)
Sphalerite Wurtzite	Zn, S, also Fe, Cd, Mn, Ge		Greenockite	Wad Psilomelane Pyrolusite		Hemimorphite Sauconite Zincian montmorillonite	Smithsonite Hydrozincite Aurichalcite	Goslarite Gypsum
Pyrite Marcasite	Fe, S, also Co and As	Sulfur(?)		Limonite Hematite	Erythrite Vivianite			Melanterite Copiapite Gypsum
Chalcopyrite	Cu, Fe, S, and Ag	Copper	Bornite Chalcocite Covellite	Tenorite Cuprite Limonite			Malachite Azurite Aurichalcite	
Millerite	Ni, S		Bravoite Violarite				"Honessite"	
Dolomite	Mg, Ca, C, O							Epsomite
Calcite	Ca, C, O, also Mn			Wad Psilomelane Pyrolusite			Calcite (travertine) Aragonite	Gypsum
Quartz	Si, O, also Au					Hemimorphite Sauconite Zincian montmorillonite		

composition of marcasite and pyrite in vadose water. This probable decomposition of marcasite can be indicated by the following equations (Bateman, 1942, p. 245):

$$FeS_2+7O+H_2O \rightarrow FeSO_4+H_2SO_4$$
$$2\ FeS_2+15O+H_2O \rightarrow Fe_2(SO_4)_3+H_2SO_4$$
$$2\ FeSO_4+H_2SO_4+O \rightarrow Fe_2(SO_4)_3+H_2O$$

The ferric sulfate from the pyrite and marcasite oxidation readily attacks the sphalerite to form zinc sulfate as follows (Lindgren, 1933, p. 852):

$$ZnS+4\ Fe_2(SO_4)_3+4H_2O \rightarrow ZnSO_4+4H_2SO_4+8\ FeSO_4$$

And the freed H_2SO_4 continues the decomposition of more ferrous sulfate.

The ferrous and ferric sulfates readily oxidize to the ferrous hydroxide:

$$6FeSO_4+3O+3\ H_2O \rightarrow 2\ Fe_2(SO_4)_3+2\ Fe(OH)_3$$
$$Fe_2(SO_4)_3+6H_2O \rightarrow 2\ Fe(OH)_3+3H_2SO_4$$

Ferrous hydroxide by partial dehydration yields limonite (Emmons, 1940, p. 117):

$$4\ Fe(OH)_3 \rightarrow 2\ Fe_2O_3+6\ H_2O \rightarrow 2\ Fe_2O \cdot 3\ H_2O+3\ H_2O$$

The limonite is in two forms, indigenous and transported. The indigenous limonite directly replaces the iron sulfides, forming pseudomorphs, and the transported limonite is deposited in adjacent rocks or farther below in the zone of secondary ores. Zinc sulfate reacts with calcite of the limestone walls and the calcite of the veins is changed to zinc carbonate in one or both of the following methods (Lindgren, 1933, p. 852; Emmons, 1940, p. 394):

$$Zn\ SO_4+Ca\ CO_3 \rightarrow Zn\ CO_3+Ca\ SO_4$$

or

$$Zn\ SO_4+Ca\ CO_3+2\ H_2O \rightarrow Zn\ CO_3+Ca\ SO_4 \cdot 2\ H_2O$$

Some zinc is carried away and precipitated as zinc carbonate elsewhere, or forms in a few places other zinc minerals. Likewise, most of the calcium sulfate formed apparently has been removed in solution, but a little is precipitated as gypsum in nearby fractures. In some places a direct replacement of sphalerite by smithsonite results in pseudomorphs that retain the original euhedral form of the sphalerite crystals. Smithsonite also is as porous, cellular masses, locally called "drybone", that line and fill fractures and replace calcite or dolomite (fig. 57). When in the form of drybone the zinc nearly everywhere has been carried a short distance before redeposition as the carbonate. Smithsonite so resists further alteration that in places it has been carried away by erosion and concentrated in placer deposits. However, much smithsonite that entered the zone of extreme leaching or gossan because of the erosion of the overlying rocks has undoubtedly been broken up by weathering, and some of the zinc redissolved and removed by surface and descending vadose waters.

Lead, in contrast to zinc and iron, shows very slight mobility in the oxidized zone especially in limestones and dolomites. The galena remains unaltered except for coatings of gray or white lead carbonate (cerussite) and lead sulfate (anglesite). The only other known lead mineral is pyromorphite which is in minute quantities at a few localities. All salts of lead are difficultly soluble, particularly in the slightly basic or nearly neutral meteoric waters of carbonate rocks. Lead carbonate is least soluble, the sulfate somewhat more, and the chloride the most soluble. Galena is attacked by dilute H_2SO_4 to a small extent, especially if H_2SO_4 is combined with ferric sulfate. The first change is usually to anglesite, probably by one or both of the following reactions (Bateman, 1942, p. 246):

$$PbS+H_2SO_4 \rightarrow PbSO_4+H_2S$$

or

$$PbS+Fe_2(SO_4)_3+H_2O+4O \rightarrow PbSO_4+2FeSO_4+H_2SO_4$$

The sulfate changes within a short time to the carbonate:

$$PbSO_4+H_2CO_3 \rightarrow PbCO_3+H_2SO_4$$

or

$$Pb^{++}+SO_4^{--}+Ca^{++}+CO_3^{--}+2H_2O \rightarrow PbCO_3+CaSO_4 \cdot 2H_2O$$

Lead sulfate is very uncommon in the district, and possibly a direct reaction with limestone and oxygen in vadose water takes place as in the following reactions:

$$PbS+CaCO_3+2O_2 \rightarrow PbCO_3+CaSO_4$$

or

$$PbS+H_2CO_3 \rightarrow PbCO_3+H_2S$$

By either process, lead carbonate is formed both as gray and white coatings which surround and protect the galena, and less commonly as small clear, colorless, crystals that coat the surface of the galena. Very little galena has altered except small grains and the borders of the large crystals. Large quantities of lead carbonate were seldom found even in the shallowest lead mines. A little lead has been dissolved and carried away in solution, as is indicated by small hexagonal crystals of grayish white chlorophosphate of lead (pyromorphite) that infrequently coat other minerals away from the original galena. Phosphorus was probably obtained from small phosphatic nodules in certain beds of the Decorah formation. Reduction with galena has released free sulfur which has been deposited in a few places as clear yellow crystals in cavities within the galena.

Residual masses of galena with a carbonate coating are found in large quantities in gossans and in oxidized veins. Also, considerable amounts have been removed by streams and transported into the valleys to be concentrated as placer deposits in natural riffles in the stream beds.

Chalcopyrite shows oxidation effects similar to sphalerite and marcasite. Supergene copper minerals are deposited in and below the zone of leaching, mainly as a variety of oxides and carbonates. Dolomite and calcite are the principal minerals of the wall rocks. Reaction of the wall rocks with the copper sulfate produced in primary oxidation caused copper carbonates to form before migration occurred to a great extent. This deposition of carbonates probably prevented much supergene sulfide enrichment below the water table even where copper was quite abundant. In a few places zinc and copper in solution reacted with limestones to form the double zinc-copper carbonate aurichalcite.

Nickel sulfide (millerite) has altered to the nickel iron sulfides (bravoite and violarite) by direct replacement; the iron probably obtained from ferric sulfate in solution formed from the decomposition of marcasite. Nickel sulfate (honessite) was formed by oxidation from violarite and bravoite and replaced them or was deposited as crusts and stains on the adjacent calcite.

Barite is completely unattacked by oxidation and appears just as unaltered at the surface as at depth. It is chiefly in primary deposits but, like galena, it is also found locally in residual and placer deposits.

Most calcite gangue is dissolved and carried away but some is redeposited as travertine above water table. In some places, however, calcite is replaced by limonite and smithsonite which form pseudomorphs (fig. 57). Locally the calcium carbonate is redeposited in openings as aragonite. Also, it reacts with many of the minerals described above to form their carbonates.

ZONE OF ENRICHMENT

Secondary oxides.—Near the fluctuating water table some minerals formed by oxidation such as smithsonite increase notably in quantity. Smithsonite in this lower zone commonly is white and is as well-formed crystals or crystallized incrustations. Where copper is present in the ores, quantities of copper oxides and carbonates are deposited with this smithsonite (for example, Eberle mine near Highland, Wis.). Some sphalerite and marcasite in all stages of oxidation generally remain. Many of these mixed ores, though rich, have remained unmined owing to the difficulties in separating the sphalerite from the smithsonite.

Several minerals that are generally not seen elsewhere are noted in this zone. Further oxidation probably removes them, and they are not present after the original sufides have been oxidized. Some of these minerals are formed from impurities that have been dissolved from the primary sulfides. Wad, psilomelane, and pyrolusite are derived from sphalerite and calcite; erythrite is derived from an arsenic-cobalt mineral in marcasite; aurichalcite (copper-zinc carbonate) is formed from chalcopyrite and sphalerite; and the soluble sulfates melanterite, copiapite, and goslarite are formed from galena and sphalerite. Accompanying these minerals locally are cavities containing brittle, waxy, brown tallow clays of which there are two types, sauconite, containing about 22 percent zinc oxide, and zincian-montmorillonite carrying about 4 percent zinc oxide. Similar tallow clays have been seen above in the leached zone and away from ore bodies, but it is not known if they also contain zinc.

Secondary sulfides.—Secondary sulfide enrichment is an unimportant feature of the ore bodies. Copper deposits and copper-bearing zinc deposits contain supergene copper sulfides. Chalcocite, bornite, and covellite are the principal secondary enrichment minerals. The areas of enrichment are local and lie near the zone of the fluctuating water table, which changes slightly owing to varying seasonal precipitation. The secondary sulfides are commonly intermixed with partly oxidized primary copper, iron, and zinc sulfides, and in places with copper and zinc carbonates and oxides. The secondary copper sulfides replace primary chalcopyrite and sphalerite, and in places they fill cavities and form veinlets. Large quantities of supergene chalcocite and covellite were noted by the writers in drill hole samples at the McIlhon zinc deposit near Mineral Point, Iowa (Terry, 1948). The chalcocite and covellite replaced chalcopyrite and sphalerite and are most abundant near the top and sides of the ore body accompanied by abundant pyrite and marcasite.

Despite a careful search for lead or zinc sulfide deposits showing evidences of secondary sulfide enrichment, few signs of such deposits were noted in any of the many ore bodies studied except for stains of greenockite and very locally, violarite and bravoite. Nowhere in the abundant cavities and open veins were deposits of lead and zinc sulfides noted on surfaces of the last-deposited primary calcite crystals. Secondary galena and sphalerite were not observed in mines reopened after many years of being flooded, although the writers very carefully searched the walls where vadose waters descended, pools where ground water collected, and numerous iron and copper implements left in the mines when they were closed. Iron hydroxides and several sulfate minerals were deposited in many places where meteoric waters passed. Fragments of sulfides were found cemented to iron tools, but they were cleavage fragments or fragments of crystals cemented to the iron by an iron hydroxide coating.

The sulfide stalactitic forms are deposits of primary minerals, even though they resemble surficially cave travertine deposits. They are everywhere direct outgrowths of regular-banded primary veins and show, without change, the same paragenetic sequences and crystal habits as the primary veins. Also most stalactitic forms found in place point upward, and all have central tubes; thus their formation by falling drops in open cavities is improbable. Some stalactitic forms have the central tube partly filled with sulfides different from those of the walls, but in each example the sulfides are the next younger ones in the regular primary mineral sequence of deposition. They were probably deposited in the open tube after deposition of the minerals that formed the stalactite walls had ceased. Furthermore, in some places the same minerals are not only in the central tube but have been deposited in their regular order on the outside walls as well.

The only supergene sulfides observed other than those of copper and cadmium are the minerals violarite and bravoite. These minerals are secondary nickel iron sulfides formed by meteoric waters from millerite near the ground water table. The violarite and bravoite are direct pseudomorphs of millerite, coat chalcopyrite crystals, and form micro-crystal molds or clusters surrounding acicular cavities that formerly contained millerite crystals. Part replacements of millerite are also common. The supergene sulfides were mostly deposited as direct replacements of the millerite or as descrete grains at a distance of less than 1 millimeter from millerite from which they were derived.

GEOLOGIC PRINCIPLES APPLIED TO EXPLORATION AND MINING

OLDER PROSPECTING METHODS

The Indians and other early prospectors originally discovered the lead deposits by outcrops of ore and by residual and float galena found in the soil or in streams below the mineralized areas. Such discoveries usually were adjacent to valleys. The known ore-bearing joints were traced away from the valleys by prospecting with shallow pits, and the characteristics of the deposits, and especially of the gossans, became known. Also, plants that thrive on the peculiar soils and increased moisture above the mineralized joints were used as indicators in some places. Included among these plants are the cottonwood, red cedar, and white birch trees, and the wild peas, *Baptisia bracteata* and *Amorpha canescens*. In some localities the lushness of the vegetation alone in lines across the prairies indicated the presence of a joint. As more of the land came under cultivation, plowing sometimes revealed the brown clays and associated residual galena that is present locally along mineralized joints. Such places were prospected and developed frequently by the farmers, who turned to mining during the winter months.

Some of the early prospectors and miners unknowingly discovered some of the pitch-and-flat zinc deposits that later contributed appreciably to the production of the district. For example, the upper parts of the deposits at the Black Jack mine in Illinois, and at the Kennedy, Helena-Roachdale, Little Giant, and Coker mines in Wisconsin were mined for galena and the associated zinc minerals were discarded. Later these zinc occurrences were remembered and the deposits were developed into zinc mines. Other zinc deposits in the lower ore zone were also discovered unintentionally when long adits were driven beneath lead deposits to drain them. In this manner the deposit at the Galena Level mine near Shullsburg, the shallow zinc deposits at Tennyson, and several other deposits were discovered.

The methods of prospecting changed when zinc displaced lead as the major metal of the district. By 1900 the prevalent method of exploration was churn drilling. Locations were chosen for prospecting because of the presence of old lead pits or because of signs of zinc mineralization on the surface. Much of this prospecting was unsystematic; locations of holes were made haphazardly with no attempt to follow structure or alteration; and the positions of most of the holes and the results of the drilling were soon lost because no records were kept. This lack of system undoubtedly caused duplication of drilling in many areas. Many ore bodies were found, however, probably because of the close spacing of deposits in the favorable areas.

In the early 1900's Grant, Bain, and other members of the Wisconsin and Illinois Geological Surveys produced detailed geologic structure maps which were among the first of their kind. These maps were a great aid in prospecting, particularly for east- and northeast-trending zinc ore bodies, which were the most common. Grant and Bain also recognized and pointed out the relationships of the zinc ore bodies to synclines. As a consequence, exploration was conducted on a more systematic basis, and new and important ore bodies were discovered at depth in areas away from the valleys and where there were no surface indications. The Vinegar Hill Zinc Co. was one of the companies that was more advanced in their exploration methods, as is shown by their record of ore body discoveries. This company restricted much of its primary prospecting in an area to churn drilling along north-trending lines, because such lines of holes would most likely strike both east- and northeast-trending ore bodies. The Vinegar Hill Zinc Co. also recognized the value of subsurface information, even that from barren ground, and kept accurate records of all drill holes. These records contained the locations and elevations of the holes as well as the depth to, and the nature of, the favorable or marker beds. These data were used to determine the structure and to locate new drill sites. Other companies used similar methods, but most were not as successful as the Vinegar Hill Zinc Co. in carrying out the program.

Little prospecting was done after 1906 in the beds which lie beneath the Spechts Ferry shale member because of the theories of ore deposition of Grant, Bain, Cox, and others. For the same reason, areas capped by Maquoketa shale were not prospected until O. E. DeWitt of the Vinegar Hill Zinc Co. explored such an area and discovered the large ore body that later became the Crawford mine.

The search for new ore bodies in the district continued until the late 1920's when many of the companies ceased their activities. A few, however, remained active and continued their prospecting with successful results. In the early 1940's discovery of a large ore body in Illinois by the cooperative efforts of the U. S. Bureau of Mines, the U. S. Geological Survey (Lyons, Heyl, and Agnew, 1949, p. 106–107), and the Illinois Geological Survey, plus the impetus of the war effort, resulted in the initiation of rather intensive exploration programs by several companies. Exploration of large areas by drilling on a grid pattern, usually with 330, 660, or 1320 foot centers, was introduced into the district, and a number of new ore bodies were discovered by this method (Ewoldt and Reynolds, 1951, p. 230–231). Diamond drilling was tried by the U. S. Bureau of Mines (Zinner and Lincoln, 1946; Kelly, 1948, 1949), by the U. S. Geological Survey (Heyl, Lyons, and Agnew, 1951), and by several companies to explore both for zinc deposits and for gash-vein lead deposits. Diamond drilling was found to be more expensive than churn drilling and recovery of cores from mineralized or altered rock commonly was low. Several methods of geophysical prospecting were tried during the 1940's and earlier by Government agencies and private companies. No discoveries were made as a result of these geophysical programs, but some interesting data were obtained. Experiments with geochemical prospecting in this district have given promising results (Kennedy, (1956)).

STRATIGRAPHY AND STRUCTURE AND OTHER FEATURES AS GUIDES TO EXPLORATION

As in many mining districts, various features and characteristics of the stratigraphy, structure, alteration, and mineralization are useful and necessary aids and guides in prospecting and exploration. The writers of this report participated as advisers in the U. S. Bureau of Mines drilling program in the Upper Mississippi Valley zinc-lead district and thus had an opportunity to try out and test such guides as might be useful in exploration. Some proved to be of little value, and even misleading, and were discarded, whereas others proved useful. These last are discussed and described in the following pages.

STRATIGRAPHY

USEFUL MARKER STRATA

The highest prominent marker horizon in the Galena dolomite is the uppermost chert which is the top of the Prosser cherty member and is 110 feet below the top of the Galena dolomite. This chert occurs as separate nodules. The top of the marker usually can be determined to within 2 feet of its actual position. It is possible to distinguish the trends of the principal folds by drilling only to this cherty zone, although the structure is more subdued at this horizon than in the lower formations.

The Prosser cherty member of the Galena dolomite contains a number of regular and, at least in the southern half of the district, persistent zones of strata which are defined on the basis of the presence or absence of chert and *Receptaculites*. These zones are perhaps not as satisfactory markers as some of the beds of the lower formations, but they are useful where the lower formations are concealed. The zones are designated in the section from top to bottom as they will be penetrated in this order by prospect drilling. The zones are as follows starting at the topmost chert in the Prosser cherty member:

(1) *Upper cherty beds.*—About 5 feet of strata sparse in chert at the top, and 27 feet of very cherty beds. A thin shale layer is present about 25 feet below the top of the unit. Seven feet below the shale is a second thin, brownish shale layer, sometimes with orange-colored bentonite, which is a better marker than the first shale layer.

(2) *Middle noncherty beds.*—Twenty feet of noncherty beds except for a single, persistent heavy chert band or a 2- to 3-foot zone of very abundant chert nodules which is present about 10 feet below the top of the unit. Locally the basal beds contain *Receptaculites.*

(3) *Middle cherty beds.*—Ten feet of strata in which chert bands are common.

(4) *Lower Receptaculites beds.*—A zone of noncherty beds, 12 to 15 feet thick, commonly thick bedded. *Receptaculites* are abundant throughout the unit.

(5) *Lower cherty beds.*—Ten feet of thin, wavy beds of dolomite with chert nodules especially abundant near the top.

(6) *Lower buff beds.*—The basal unit of the Prosser, 10 feet thick, which is noncherty. Yellowish-green patches and thin layers of argillaceous material occur in it.

The top of the Decorah formation is marked by light- and dark-gray dolomite mottled with small dark-gray or black specks, and by a thin green shale layer. The gray beds of the Ion member are 14 to 15 feet thick, and the blue beds beneath are 6 to 7 feet thick; the two units are separated in most places by a 2- to 4-inch greenish shale layer. The gray beds are lighter in color and contain fewer green shale partings than the blue. The blue beds contain rounded quartz sand grains scattered throughout and, in places, small black, phosphate nodules in the basal beds. Within and adjacent to some ore bodies the Ion member has been slightly thinned by partial removal of dolomite beds by the mineralizing solutions. Accompanying the thinning is an increase in the greenish-blue-shale content.

The contact between the Ion and Guttenberg members is conformable, and a transition zone about 2 feet thick is present. The top of the Guttenberg is marked by a chocolate-brown shale layer, which commonly is in the upper part of the transition zone where it is interbedded with dolomite similar to that of the blue beds. The base of the Guttenberg is distinguished by several 6-inch, gray-blue, massive limestone beds that contain phosphate nodules in most places.

The thickness of the Guttenberg may be decreased to as little as 4 feet, but more commonly to about 10 feet, by removal of the limestone beds by the mineralizing solutions and concentration of the brown shale residues. Such alteration is not necessarily accompanied by ore deposition, although small quantities of sulfides commonly are present. Thinning and shalification of this type are almost always present, however, in and adjacent to the pitch and flat zinc ore bodies, and this type of alteration is very useful in prospecting.

Locally, dolomitization and silicification, which are closely associated with the ore deposition, also affect the Guttenberg limestone member, and generally thinning and shalification are then less prominent, although always present. Coarse dolomite grains, sanded dolomite, and an abundance of chert, jasperoid, and cotton-rock are indications of dolomitization and silicification. These two types of alteration, like thinning and shalification, are very useful in prospecting.

The basal member of the Decorah formation is the Spechts Ferry shale member, locally called the clay bed. This unit is a plastic, apple-green shale which in some places contains thin, pinkish, wavy layers of extremely fossiliferous limestone. Phosphate nodules are present at the top of the member in both the shale and the limestone. A two inch, white to creamy yellow bentonite layer occurs near the base of the member. The thickness of the Spechts Ferry ranges from zero in the eastern part of the district to 6 or 7 feet in the western part.

The top member of the Platteville formation is the Quimbys Mill member or locally-called glass rock. This unit consists of salmon-pink to brown, dolomite or sublithographic limestone with interbedded chocolate-brown, carbonaceous shale partings. At the base of the Quimbys Mill is a dark brown, carbonaceous shale layer, 6 inches thick. The Quimbys Mill reaches a thickness of 14 to 15 feet in the eastern and southern part of the district and thins to a foot or is absent completely in the nothern and western part. The Quimbys Mill is a distinctive marker, but it may be easily confused with the Guttenberg member.

The ore solutions have altered the Quimbys Mill in places by thinning, shalification, dolomitization, and silicification. The rock, where dolomitized, is a sanded dolomite, brown to reddish brown in color, and not easily distinguishable as the Quimbys Mill.

The McGregor limestone member consists of 30 feet of limestone which, in the lower part, is similar to the wavy-bedded limestone of the Guttenberg except that it is mottled and gray in color. Gray, greenish, and light brown shale partings are present throughout the McGregor. In some places the ore solutions have thinned the beds and altered them to greenish-gray shales containing lenticular, white, limestone nodules.

The Pecatonica dolomite member is a light-gray and brown, medium-grained dolomite in beds from 1 to 2 feet thick. The beds are easily distinguished from those of the overlying McGregor, and the contact between the Pecatonica and McGregor is a good marker horizon. The basal beds of the Pecatonica contain rounded quartz sand grains and phosphate nodules.

The Glenwood shale member, which is the basal member of the Platteville formation, is an excellent marker. The unit is 2 to 3 feet thick and consists of green shale containing abundant, rounded quartz sand grains and grading into sandstone toward the base.

The St. Peter sandstone is easily identified and its top is a good marker horizon.

DEPTHS TO WHICH DRILLING SHOULD PROCEED

In the past little prospecting was done beneath the Spechts Ferry or Guttenberg members which, according to the then-accepted theory of ore solutions moving downward, formed an impervious layer preventing deposition in the lower beds. Also, the Quimbys Mill member locally contains large quantities of water, and prospecting was stopped before this unit was entered to prevent later flooding of the mine.

Large and important deposits are now known to be present in the Platteville formation well below these units. In any drilling program, therefore, the holes should at least penetrate the McGregor limestone member, particularly if any of the units are altered, such as by thinning and shalification. Deposits, in fact, have been found in the McGregor even in places where the beds above (that is, the members of the Decorah formation) were barren and unaltered.

Many of the mines at present have their floors in the Decorah formation, and the Quimbys Mill and McGregor members have been investigated in only a few of them. Such prospecting could be done easily by winzing, diamond drilling, or even, in some places, by pneumatic drilling, if care is exercised.

Little is known about ore deposits in the Pecatonica dolomite member, but this unit has been investigated even less than the McGregor limestone and Quimbys Mill members. However, probably owing to its dolomitic lithology, the Pecatonica was less receptive to ore deposition than other units, and if the overlying rocks are barren or have only poor showings, drilling into the Pecatonica would not be warranted.

Deposits in the Lower Ordovician and Cambrian strata are not uncommon, especially in the northern part of the district, and some investigation has been done in these rocks (Heyl, Lyons, Agnew, 1951). However, too little is known at the present to formulate helpful criteria for prospecting these units in the central and southern parts of the district, where they are under deep cover.

PROSPECTING BENEATH MAQUOKETA SHALE

A Maquoketa shale cover has no bearing on the presence of mineralization in the underlying beds. In several places large ore bodies have been found in the Galena, Decorah, and Platteville formations beneath the Maquoketa shale. There is a good probability that ore deposits occur beneath the shale and younger rocks to the southwest, south, and southeast beyond the present boundary of known ore deposition (Heyl, Lyons, Agnew, Behre, 1955). To date, however, the discoveries beneath the Maquoketa shale have been largely extensions of the mineralized areas not covered by the Maquoketa. Few attempts have been made to prospect systematically by any method far back from the known edge of the district to find new deposits.

STRUCTURE

The present study has emphasized the importance of utilizing the geologic structure of the district for delimiting areas favorable for prospecting and for discovering extensions and undiscovered parts of ore bodies beyond, beneath, and above old mine workings. The extent and magnitude of the structure varies in different parts of the district, and this in turn has a direct bearing on the types and distribution of ore bodies.

IMPORTANCE OF FOLDS OF FIRST ORDER

The locations of the ore deposits appear to be controlled in a general way by the first-order folds of the district (pl. 1, 8), particularly in the northern one-half. The most heavily mineralized areas of the district are within and follow the larger synclines in part. For example, the Crow Branch mine southwest of Livingston, Wis., is adjacent to the axis of a large syncline which trends east-northeast for 20 miles past the south edge of Dodgeville, Wis. Associated with the axis of this syncline toward the east from the Crow Branch mine are the Coker mines, the mines in the Linden area, and those in the Dodgeville area, all heavily mineralized areas. Similarly, a large syncline extends from Potosi, Wis., eastward through Platteville and Calamine. Large and important deposits seldom are situated near the crests of large anticlines. This relationship is particularly apparent between Beetown and Lancaster, Wis., and also is discernible in anticlinal areas in many other parts of the district.

In the southern part of the district most of the principal mining areas lie on the gentle south limb of the Meekers Grove anticline extending east from Sherrill, Iowa, through Jamestown and Cuba City, Wis. On this south limb from east to west are (1) the mines near Dubuque, Iowa, (2) those near Sinsinawa, Wis., and (3) the most concentrated mining center of all, that between Hazel Green and Shullsburg, Wis. (pl. 1). This last area lies south of and is partly enclosed by a marked northward bow in the Meekers Grove anticline. An extension of the Hazel Green-Shullsburg mining area to the southwest into Iowa along Tete des Morts River follows, in part, a southwest-trending syncline passing through Galena, Ill. (Willman and Reynolds, 1947).

It should be noted that along or adjacent to the various structural trends both in the north and south parts of the district, are areas which are underlain by the zinc ore-bearing zones, but which have been very little prospected. For example, the Van Matre's or North Survey area on the synclinal trend between Linden and Dodgeville, Wis. is an area of concentrated mineralization, as is evident from the numerous lead diggings, which has been prospected very little for zinc. Along the Potosi-Platteville-Calamine, Wis. synclinal trend are areas of high, level ground and thick cover which lack good outcrops, but which have scattered lead mines. These have been very little investigated. Similar areas of mineralization that have not been much prospected for the deeper zinc deposits, but in which zinc is known to occur, are the Beetown, Wis. district (Heyl, Lyons, Theiler, 1950) and the Pigeon diggings two miles southwest of Lancaster, Wis., both associated with the same synclinal trend; the Menominee diggings at Louisburg, Wis.; and the mines at Dubuque, Iowa.

IMPORTANCE OF FOLDS OF SECOND ORDER

Second-order folds are of importance in localizing ore bodies, particularly in the south-central and southern parts of the district where the structure is more complex. In these parts the ore bodies show, in many places, a definite relation to the second-order synclines. These synclines trend northwest, northeast, and east.

Along the northwest synclines the ore bodies are linear and tend to strike nearly parallel to the strike of the secondary folds. Barren areas 1,000 to 2,000 feet long generally separate the workable ore bodies. The secondary synclines persist through these barren areas, but are less well-defined. Some examples of northwest-trending folds are:

(1) The syncline northeast of Meekers Grove, Wis., (pl. 3) that trends N. 45° W. from the Vandeventer mine to the Connecting Link No. 1 mine. The areas northwest of the Connecting Link No. 1 mine and southeast of the Vandeventer appear to be favorable areas. The syncline northwest of Shullsburg, Wis., along which are located the Boyle, DeRocher, and Paquette mines (pl. 5) may be the southeast extension of this fold. If so, the area between these two synclines may be considered favorable for prospecting.

(2) The Kennedy syncline is one mile east of Hazel Green, Wis., (pl. 5) and trends N. 20° W. for a known length of 6 miles. This syncline contains several of the largest and most important ore bodies in the district. Recently this fold or its extension has been prospected by several companies.

(3) The Frontier syncline is a mile and a half east of the Kennedy syncline (fig. 19) and trends N. 13° W. The Frontier mine at Benton and, to the south, the Jack of Clubs, Longhenry, and Strawberry Blonde mines are located along it. From this last mine south to the Illinois State line the fold has not been prospected, but an ore body was discovered in the 1940's just south of the state line.

(4) The Bautsch-Black Jack "trough" is south of Galena, Illinois (Willman and Reynolds, 1947, pl. 4) and contains four important ore bodies, the Black Jack, Pittsburg, Gray, and Bautsch. The Gray and Bautsch ore bodies were discovered in the early nineteen forties by applying the theory of synclinal control (Lyons, Heyl, Agnew, 1949, p. 106–107). The drilling was done by the U. S. Bureau of Mines (Zinner and Lincoln, 1946) in cooperation with the U. S. Geological Survey and the Illinois Geological Survey. This syncline may extend to the north and south, but the results of studies by the Illinois Geological Survey are somewhat indefinite as to its extension (Willman, H. B., 1945, oral communication).

The northeast-trending synclines cross those trending northwest at nearly right angles. The ore bodies along the northeast-trending synclines are commonly of the arcuate type, localized in small (third-order), east-trending synclines, and in echelon and arrangement along the length of the second-order folds. Examples of these northeast-trending structures are:

(1) The Crawford-Martin syncline (pl. 5) trends N. 70° E. through the southern part of Hazel Green, Wis. Favorable areas for prospecting along this syncline may be found both northeast and southwest of Hazel Green. For example, the Badger mine at the junction of the Crawford-Martin and Kennedy synclines suggests that the junction of the Crawford-Martin and Frontier synclines also might be an especially favorable locality.

(2) A complex synclinal area extends for a considerable distance northeast and southwest of New Diggings, Wis. (pl. 5). Along this structure are a large number of important arcuate ore bodies, especially northeast of New Diggings. To the southwest in Wisconsin, however, little prospecting has been done, although a very favorable area exists between the Blackstone and Old Occidental ore bodies. Farther to the southwest the probable extension of this syncline into Illinois has been prospected in the vicinity of the Vinegar Hill mine, but the structure probably continues to the southwest, as is evidenced by a line of lead diggings, and this area has not been explored.

(3) The Galena syncline trends N. 55° E. through Galena, Ill., to Council Hill Station, Ill., where one branch continues on the same trend into Wisconsin and a second turns eastward toward Scales Mound, Ill. This structure also extends southwestward from Galena, Ill., into Iowa (pl. 3). Little prospecting at depth has been done along this syncline, although some zinc

ore has been found in those places where it has been prospected.

The east-trending synclines approximately bisect the angle between the northeast- and northwest-trending folds. The best example of such a structure is the Champion-Thompson syncline immediately south of New Diggings, Wis. (pl. 5). This syncline branches immediately east of the Thompson ore body, the northern branches changing to northeast-trending synclines and the southern branch continuing in a general eastward direction. Other such folds contain the Blockhouse Range near Platteville and the Clark Range near Highland, Wis.

After 1947 several large ore bodies were discovered in the area south of Shullsburg, which extended to the east and south from the older Hazel Green-Shullsburg area for several miles (fig. 1). The new potential area is now known to extend from the south limits of Shullsburg, Wis., southward to Scales Mound, Ill., and for a few miles east of a north-trending line between these two towns. East-northeast of Shullsburg the Galena dolomite contains few lead ore deposits suggesting that this area is relatively barren of ore. Prospecting between Shullsburg and the Rodham mine to the northeast has not been favorable to date. South and southeast of Shullsburg toward Apple River and Warren, Ill., numerous lead diggings plus possible extensions of second-order folds from the west indicate that an important extension of the district might be found in this area.

SUGGESTED METHODS OF PROSPECTING

The most common method of prospecting in the district is by drilling. A preliminary geologic study usually helps in planning a drilling program and often saves needless and expensive drilling.

PROSPECTING FOR ZINC ORE BODIES

If the general trends and locations of the folds that control the zinc ore bodies are known in the area to be prospected, lines of drill holes at right angles to the trends of the folds yield the best results. The drill holes should not be more than 50 or 100 feet apart, and the distances between the lines of drill holes should be slightly less than the average length of the known ore bodies in the area.

If the structural relationships are not known, and if there are no, or only a few, known ore bodies in the area to be prospected, the most feasible method of prospecting is to drill the area on a grid pattern. A spacing of 1,000 to 1,500 feet between the initial drill holes has been found successful in the southern and central parts of the district where the structures and ore bodies are relatively large (pl. 8). In the northern part of the district and toward the east and west edges of the principal producing zinc areas, a smaller spacing, between 500 and 1,000 feet, probably is desirable. The basic geometrical shape of the grid pattern may be either square or diamond-shaped, both having been used successfully.

An alternative method to the grid pattern is to drill lines of holes trending north or a little east of north, such a direction being at an angle to most of the structural trends in the district.

Favorable structures or areas found by either method should be delimited by more closely spaced drilling, using either a grid pattern or lines of drill holes.

The following data or "rules" are useful in prospecting for zinc ore bodies in this district:

(1) In many places zinc ore bodies associated with secondary synclines occur where cross-folds are present.

(2) Very few pitch-and-flat ore bodies trend between north and N. 60° E.

(3) More linear ore bodies trend northwest than any other direction and are associated with northwest-trending secondary synclines (pl. 5). Of the remaining linear ore bodies, many trend east and are associated with east-trending secondary synclines. Thus the trend of most linear ore bodies is parallel to the trend of the secondary syncline with which they are associated. Therefore, exploration for new ore bodies of this kind should be ahead and on the trend of the known ore body, preferably by cross lines of holes at intervals along the structure.

(4) The trends of many of the arcuate ore bodies have en echelon relationship to the trend of the secondary syncline with which the ore bodies are associated. Therefore, exploration for new ore bodies of this kind should not in most places be ahead of and on the trend of the known ore body, but on the trend of the secondary syncline (pl. 5).

(5) Most known arcuate and elliptical ore bodies enclose synclines which have small subsidiary anticlines in their centers (fig. 50).

(6) Most known arcuate and elliptical ore bodies are east-trending, and more arcuate ore bodies have the arc on the east end than on the west (pl. 5).

(7) Most double pitch linear ore bodies have their pitch-zones closely spaced and the ore is continuous or nearly so in places from one pitch-zone to the other (pl. 20), whereas arcuate ore bodies have their pitch-zones widely spaced and have a barren central core (pl. 12). Barren cores are found in those parts of the linear ore bodies where the pitch zones are farthest apart.

(8) Exploration directly beyond the closed ends of

arcuate ore bodies is rarely successful, but extensions of ore bodies can be found in some places by drilling immediately ahead of the open ends of these arcuate ore bodies.

(9) Many pitch-and-flat zinc ore bodies associated with secondary synclines are spaced at fairly regular intervals along the axis of the syncline, and this regularity of spacing may be used in some places to locate favorable prospecting areas (pl. 1, Black Jack mine and others to southeast).

(10) Most of the pitches dip southward in those pitch-and-flat ore deposits where only one pitch is known.

(11) The top of the Guttenberg limestone member, especially where the rock is altered by thinning and shalification, is the best marker horizon in the section. Structure contours drawn on this horizon also give the most detailed structure pattern for prospecting.

(12) Areas in which wide-spaced drilling reveals numerous occurrences of sulfides as well as thinning, shalification, and local dolomitization and silicification of the Decorah and upper Platteville strata should be prospected with closely spaced drill holes for possible commercial deposits of ore.

(13) Areas in which the Galena dolomite is mineralized but in which the Decorah and Platteville are unaltered and barren of sulfides are commonly unfavorable for pitch-and-flat zinc ore bodies.

(14) Abundant concentrations of lead ore in the Galena dolomite in the central part of the district are favorable prospecting areas in many places, and a number of these areas have been investigated. Many of the recently discovered ore bodies have been found near, but to one side of, the galena-bearing areas. In places, however, areas having very few surface indications of ore have been found to have important zinc deposits at depth.

(15) Areas underlain by the Galena dolomite and containing few surface indications of ore may be surrounded by ore outcrops and shallow mines. Such areas probably contain hidden zinc ore deposits.

(16) The presence of several large ore bodies in a limited area surrounded by unprospected land (pl. 2) strongly suggests that other large ore bodies exist in the unprospected area.

PROSPECTING FOR LEAD ORE BODIES

The possibility of developing lead mines comparable in size to the larger zinc mines of the district is not too good. Although the gash-vein lead deposits remaining in the district are probably abundant, most of these are best suited to small scale operations. In some areas galena is highly concentrated in closely-spaced joints that have been mined only to the water table as, for example, near Hazel Green, Benton, New Diggings, Shullsburg, Wis., Galena and Elizabeth, Ill., and Dubuque, Iowa. Such areas might be developed on a large scale below the water table, but the financial risk entailed in development would be greater than with most mining ventures. Shaft sinking and mass sampling of the ore bodies is the only method known that might be potentially successful in prospecting worked-over areas of gash-vein deposits. Drilling will locate some of the gash veins in the areas, but it has not been successful to date (1955) in developing measurable reserves or in determining the average grade of ore.

The best example of a gash-vein deposit that was mined successfully on a large scale is the Rodham mine (fig. 88) north of Shullsburg, Wis. The deposit was located and partly developed by churn drill holes drilled in north and east lines. Individual holes on these lines were commonly spaced as close as 25 feet apart in order not to miss the gash veins. Even after the deposit was drilled in this way, the grade and tonnage of ore could not be successfully estimated (DeWitt, O. E., written communication, 1947), but these data were determined only after the ore body was mined. Large scale production was achieved by careful stoping along the ore-bearing joints, and the barren rock between the intersecting joints was left as pillars.

Other such bodies of close-spaced and intersecting gash veins may occur undiscovered in the large areas capped by Maquoketa shale in the southern part of the district. Such untouched areas of gash veins, if found, may be amenable to mining methods similar to those used at the Rodham mine.

Probably the best method for finding new gash-vein lead deposits near old lead mines is to prospect ahead of known ore-bearing joints beyond the point of previous prospecting and mining. In a particular area the ore-bearing joints are remarkably persistent in their trend, and there may be more than one parallel set (pl. 7). The area of intersection of two ore-bearing joints is known as a "crossing" and often is more heavily mineralized than other parts of the joints. The trends of ore-bearing joints are often very apparent in aerial photographs.

Indications of the presence of mineralized joints are residual galena in the fields, placer galena in small streams, galena-bearing joints in road cuts, areas or bands of brownish soil with pieces of calcite or limonite in plowed fields.

Another method of prospecting for gash-vein lead deposits is to explore for the deeper ore below the water table along those joints already mined, especially if an appreciable thickness of the Galena dolomite is present.

Development of such deposits would entail removal of the water, either by pumping or by drainage adits.

Prospecting for gash-vein deposits by drilling has not been especially successful. Trenching with a bulldozer across the trends of the veins, followed by sinking prospect shafts at favorable spots probably is as satisfactory a method as is known. Chamberlin (1882, p. 560–567) gives various suggestions for prospecting and mining deposits of this type.

GEOPHYSICAL AND GEOCHEMICAL PROSPECTING METHODS

A number of attempts to discover ore bodies in the district by geophysical means have not had very favorable results. Magnetic, self-potential, and induced potential methods have all been tried at various times and in various parts of the district. Seismic, resistivity, and gravity methods are as yet untried.

Ordinary Gurley dip needles and Hotchkiss superdip instruments have been used in the district, but no favorable results have been obtained.

The self-potential method has been used in a number of areas. In the 1940's the U. S. Bureau of Mines and the Illinois Geological Survey conducted extensive surveys. The results obtained were, in general, inconclusive, but further attempts by this method might be warranted.

The applied or induced potential method was tried by the Illinois Geological Survey with results favorable enough that they consider additional work desirable.

Airborne and ground electromagnetic methods were tried on a large scale in 1955–56 and found notably wanting in locating mineral deposits in the district.

The U. S. Geological Survey conducted experimental geochemical studies in the district in 1947 to 1949. Water analyses for lead and zinc in the streams and springs that drain areas of known zinc deposits were compared with similar analyses from areas in which no zinc deposits were known, but which were favorable for prospecting. Similarly, soil and plant analyses were made and compared to determine if blind ore deposits could be located. The preliminary results appear promising both for locating gash-vein lead deposits and those pitch-and-flat zinc deposits that are partly oxidized (Hawkes, H. E., oral communication, 1949). Separate reports describing these studies are published (Huff, 1952, Kennedy, 1956).

USE OF STRUCTURES WITHIN THE ORE BODIES IN MINING OPERATIONS

It is necessary in some mines to follow the structure and geologic features rather closely during mining operations in order to determine the trend of the ore body and to find any extensions of ore which might have been missed in drilling. Several examples follow:

(1) If in what is believed to be a single pitch ore body, there is a rise of the beds to a definite arch in the area behind the footwall side of the pitch zone, and if some core ground mineralization is present, there is a good probability that the opposite pitch zone exists.

(2) Prominent vertical cross fractures, particularly if they have a northwest trend and show signs of deformation and mineralization along them as they pass into the mine walls, are in places signs of branch ore runs. Ore runs of this type occur in the Coker No. 1 (pl. 2), James (fig. 98) and the Dodgeville mines (pl. 10). They are especially well developed in the ore bodies in the Quimbys Mill member of the new Blackstone mine near Shullsburg, Wis.

(3) Pitch zones which pass into the roof or floor of a mine may be ore-bearing above or below the present workings.

(4) In arcuate ore bodies the pitch zone may "feather" or "horse-tail" out where the pitch zone turns at the arc. In some places only one branch of the pitch zone is followed in mining, although the other branches may contain ore beyond the apparent ore body walls. Similarly, in linear ore bodies divergence of the pitches may result in only one pitch being followed. In both instances, prospecting ahead by drifting or by drilling a few holes would quickly and cheaply indicate if the structure on the unmined side contains mineable ore.

CORRELATION OF SURFACE OUTCROPS AND DRILL LOGS AS GUIDES TO STRUCTURES AND ORE BODIES

Mapping of the surface geology, combined with information obtained from old mine maps and drill records, helps in choosing or eliminating areas for prospecting. Maps based on such data and published by the U. S. Geological Survey, as for example the map of the Hazel Green-Shullsburg area (pl. 5) (Heyl, Agnew, Behre, Lyons, 1948), have been used by companies when planning exploration programs and choosing favorable areas for prospecting. In addition correlation of surface outcrops and of drill logs while exploration is in progress is very useful in determining the nature, location, and magnitude of the structure.

USE OF GEOLOGY TO DELIMIT ORE BODIES DURING PROSPECTING

The occurrence of the ores, that is, whether in veins along well-developed pitches and flats, in disseminated form, or in solution-breccia form, as well as their mineralogic character and tenor, have an important bearing on the value and workability of an ore body. Some of this information can be obtained by drilling.

An idea of the strike and dip of the pitches can often be obtained by noting the location of local basins, the depths at which the rich ore occurs in the holes, and the depths and locations at which iron sulfide predominates. The iron sulfides and galena generally are more common at the edge of the ore body, that is, at the bottom, or "toe," of the pitches (fig. 71), and so would be relatively low in the drill holes. Farther toward the center of the ore body, the drill holes cut the pitches and ore at a higher elevation than at the edge of the ore body. Zinc minerals, rather than iron sulfides and galena, are dominant, and the marker beds commonly are at a lower elevation than toward the periphery of the ore body. The central "core ground" of an ore body commonly is indicated by considerable thickness of lean zinc sulfides accompanied by substantial quantities of iron sulfides and by the marker beds being rather high structurally.

MINES IN THE UPPER MISSISSIPPI VALLEY ZINC-LEAD DISTRICT

This description of mines operated prior to 1956 in the Upper Mississippi Valley zinc-lead district has been divided into two parts: (1) mines in the main part of the mineralized district (pl. 1), and (2) mines in outlying areas (fig. 101).

MINES IN THE MAIN PART OF THE MINERALIZED DISTRICT

Mines in the main part of the upper Mississippi Valley zinc-lead district are grouped in clusters (pl. 1), some of which, such as the Elizabeth subdistrict, Ill., exhibit sharply defined boundaries. In other places, general areas for the most part connected by mines have been arbitrarily separated into subdistricts: Galena subdistrict, Ill.; Hazel Green-Shullsburg subdistrict, Meekers Grove-Jenkinsville subdistrict, and Platteville-Big Patch subdistrict, Wis. (pl. 1).

Most zinc mines that produced ore in the district are described, but a few of the smallest mines and many prospects have been omitted. The mine shafts and workings are plotted. Many of the shallow lead mines are described in earlier reports (Owen, 1844; Percival, 1855, 1856; Whitney, 1862; Strong, 1877; Leonard, 1897; Calvin and Bain, 1900), and, except where additional data or more recent mining activity warrant it, they are not included in the following pages. The general areas of lead mines or "diggings" are shown on the maps (pl. 1) as green patches.

Some zinc deposits are intimately associated with areas of lead diggings; other zinc deposits are in areas that have few known lead deposits.

The detailed areal geology, structure, and ore bodies of parts of some of the subdistricts are shown in plates 2–21. Some reports (Bain, 1905 and 1906; Grant, 1906; Cox, 1914; and Willman, Reynolds, and Herbert, 1946) present good descriptions of many of the mines; where these data are adequate, the mines are not described in detail in this report.

Statistics on ore production are from various published sources and from the files of the mining companies; statistics from mines in Illinois are from the report by Willman, Reynolds, and Herbert (1946).

Within the southern subdistricts the mines are described according to township; within each township according to section. Thus a mine in sec. 1 is described before one in sec. 10. In other subdistricts, however, the mines are described according to proximity to previously described ones.

MINES IN ILLINOIS

ELIZABETH SUBDISTRICT

This formerly important area contains the southeasternmost large lead mines of the district (pl. 1). Only lean and small zinc deposits have been found by prospect, drilling, but little exploration of the main zinc ore zone—the Prosser cherty member of the Galena dolomite, and the Decorah and Platteville formations—has been undertaken, and the presence or absence of commercial zinc ore deposits has not been proven.

The Elizabeth subdistrict is at the southwest end of a syncline that trends N. 40° E. (Shaw and Trowbridge, 1916). Most of the lead deposits are along eastward-trending fractures within this fold. A detailed geologic map showing the location of the principal ore deposits was prepared by Cox (1914, pl. 22).

The stratigraphic sequence is similar to that elsewhere in the eastern part of the mining district. The Guttenberg limestone member of the Decorah formation is about 8 feet thick. At its base the phosphate nodules of the underlying Spechts Ferry shale member are the only remnant of that unit. The underlying Quimbys Mill limestone member at the top of the Platteville formation is about 19 feet thick.

Wishon mine (pl. 1, no. 1).—The Wishon lead mine, in the SE¼NE¼ sec. 14, T. 27 N., R. 2 E., was operated from 1865 to 1875 and from 1902 until approximately 1910. The ore body is localized along two opposite-dipping east-striking pitches near the top of the Prosser cherty member of the Galena dolomite. The stopes are as much as 150 feet wide and 50 feet high. This mine probably produced more ore than any other in the Elizabeth area. A few scattered deep drill holes were put down in its vicinity, with unfavorable results. Detailed descriptions of the Wishon mine can be found in the reports of Cox (1914, p. 59) and Bain (1905, p. 43).

Haggerty mine (pl. 1, no. 2).—This mine, in the SE¼ sec. 14, T. 27 N., R. 2 E., was described by Whitney (1866, p. 207), and later development was briefly noted by Cox (1914, p. 61).

Illinois mine (pl. 1, no. 3).—The Illinois mine, in the SE¼SE¼ sec. 23, T. 27 N., R. 2 E., was formerly an important producer of lead ore. Cox (1914, p. 60) gave a good description.

Kansas mine (pl. 1, no. 4).—Located in the SW¼ sec. 24, T. 27 N., R. 2 E., this lead mine was briefly described by Cox (1914, p. 60).

Skene mine (pl. 1, no. 5).—The large and formerly important Skene lead mine is in the southwest corner of the NW¼SW¼ sec. 25, T. 27 N., R. 2 E. The mine was operated from 1901 to 1907, and descriptions may be found in reports by Cox (1914, p. 59–60) and Bain (1905, p. 43–44).

The ore body was developed at a depth of 96 feet along westward-trending pitches that curve northeastward at the west end to form an arcuate pitch (fig. 75). These pitches are ore-bearing in the Prosser cherty member of the Galena dolomite.

In 1944 a line of five prospect holes was drilled northward across the ore body by the U. S. Bureau of Mines (Terry and Lincoln, 1948) at the suggestion of the U. S. Geological Survey and the Illinois Geological Survey to see if a deposit of lead and zinc existed at greater depth. These holes cut mineralized pitch-type fractures, but the lead and zinc ore deposits are small and lean. Lead minerals are more abundant than zinc. Evidences of dolomitization and shalification were seen in the locally-thinned Guttenberg member of the Decorah formation. The top of the Platteville formation lies 190 feet below the valley flat at the mine.

APPLE RIVER-WARREN SUBDISTRICT

This old lead mining area is the easternmost important one in northern Illinois (pl. 1). The ore bodies are in mineralized joints and openings, and at one time large quantities of lead were produced from the Stewartville massive member of the Galena dolomite. A furnace at Warren produced about 300,000 pounds of metallic lead annually from 1872 to 1876. Within recent years small tonnages of lead have been mined in this area. No known prospecting has been done to locate zinc deposits at greater depth.

STOCKTON, SIMMONS MOUND, MORSEVILLE SUBDISTRICTS

Lead ore was mined near Stockton from the upper beds of the Galena dolomite along Hammond Branch of the Plum River (pl. 1). Other small areas of lead mines are about a mile northeast of Simmons Mound and at Morseville.

SCALES MOUND SUBDISTRICT

In the vicinity of Scales Mound the dumps of several old lead mines are still visible (pl. 1). Most of these ore bodies contain galena in the topmost beds of the Galena dolomite; on the other hand, the Glanville prospect (pl. 1, no. 7) was on the basal strata of the Maquoketa shale. Some drilling for deeper zinc deposits has been done near the town of Scales Mound, and a number of holes showed zinc ore.

Rockford Mining and Milling Co. mine (pl. 1, no. 6).—This old lead mine, in the NW¼SW¼ sec. 1, T. 28 N., R. 2 E., has two shafts, about 200 feet apart, on apparently separate eastward-striking fractures. Little is known about this ore body except that it is in the Stewartville massive member of the Galena dolomite and that it was mined between 1905 and 1915.

Glanville prospect (pl. 1, no. 7).—The Glanville prospect is in the NW¼NW¼ sec. 24, T. 29 N., R. 2 E. A short drift was driven in this deposit in 1903–4, but no commercial ore was found (Cox, 1914). Some sphalerite and barite occur in thin dolomite beds near the middle of the Maquoketa shale. The minerals are in individual masses one-half to three-fourths of an inch in diameter, in small drusy cavities in both the weathered and the unweathered rock.

GALENA SUBDISTRICT

The Galena subdistrict, formerly important in lead production (Whitney, 1866), contains large zinc deposits (pl. 1). This subdistrict merges northward into the Hazel Green-Schullsburg subdistrict of Wisconsin (pl. 1). The old California diggings, which are in the Mississippi River bluffs as far south as sec. 28, T. 27 N., R. 1 E., mark the known south edge of the mining district. Although the Galena subdistrict is highly mineralized, parts of it have been relatively little prospected for pitch-and-flat zinc ore bodies, owing to the greater depth of drilling and higher initial mining and development costs.

The stratigraphic sequence is similar to that found farther north, in the central part of the district. The Galena subdistrict shows structural deformation of greater magnitude than is common farther north in the district. Among the known folds the most important ore-bearing synclines are the N. 30° W. trending Bautsch-Black Jack trough (Willman and Reynolds, 1947), south of Galena, and the N. 60° E. trending syncline containing the Vinegar Hill and other important mines just south of the Wisconsin-Illinois line about 5 miles north of Galena. A potentially important syncline, only slightly prospected, is the N. 55° E. trending Galena syncline (William and Reynolds, 1947, pl. 7), which is known to contain some ore. Northwest-

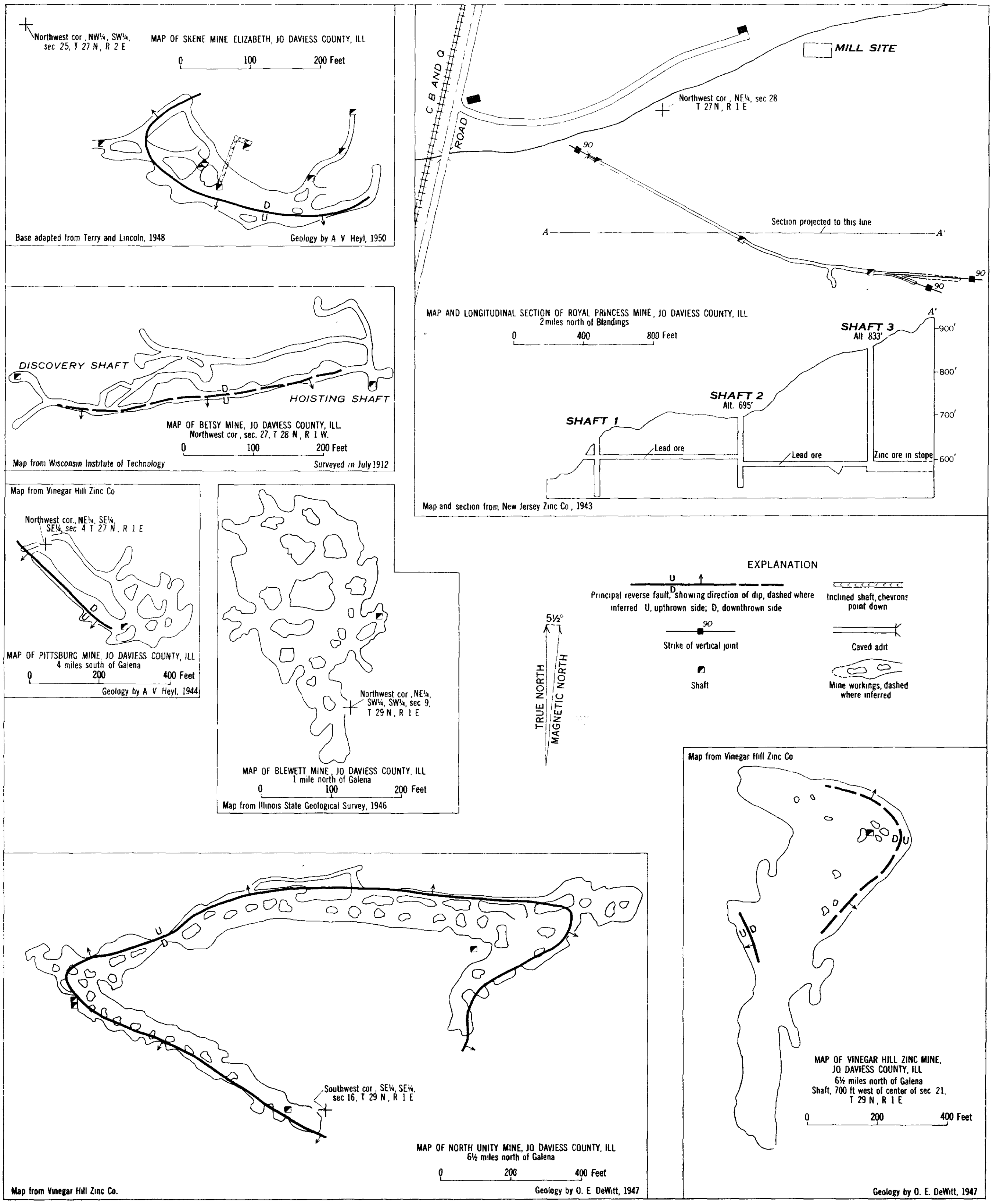


FIGURE 75.—Maps of Skene, Pittsburg (or Great Western), Betsy, Blewett, North Unity, and Vinegar Hill (zinc) mines and map and section of Royal Princess mine.

ward-trending linear ore bodies are most common in the southern part of the Galena subdistrict. At the north edge of the subdistrict eastward-trending arcuate ore bodies are most common. Some of the ore bodies are more than a hundred feet thick, and pitches and flats are well developed. Solution-thinned beds and small slump structures are prominent features of the northwestward-trending linear ore bodies.

Pittsburg or Great Western mine (*pl. 1, no. 8*).—The Pittsburg mine (fig. 75), in the northeast corner of the SE¼SE¼ sec. 4, T. 27 N., R. 1 E., was opened by the Vinegar Hill Mining Co. and operated by them in 1915 and 1916. The shaft was 152 feet deep, 2 feet above the Spechts Ferry member of the Decorah formation. More than 30,000 tons (Willman, Reynolds, Herbert, 1946, p. 37) of ore that ran between 3 and 6 percent zinc was mined. About 1,500 gallons of water per minute was pumped.

The ore body lies within the Bautsch-Black Jack trough, trends northwest, and is 10 to 40 feet thick. It is a small northwestward-trending linear ore body developed in the Guttenberg and Ion members of the Decorah formation. Only the west pitch has been mined. The east pitch can be observed in an outcrop about 600 feet northeast of the shaft but has not been prospected. The ore is rich in vein zinc ore near the shaft but is leaner to the northwest. Considerable lean ore, 150 feet in width, is in the footwall of the west pitch along the full length of the mine. In March 1916 a serious cave-in occurred at the northwest heading. A drift was then driven around this caved area through the central "core ground"—a miner's term for the ore and rock on the footwall side of the pitches—to the pitch in front of the caved heading, but as the rock there was also difficult to support, the mine was abandoned. When abandoned, the heading still showed minable, though low-grade, ore.

Marsden Black Jack mine (*pl. 1, no. 9*).—The Black Jack mine (fig. 76), formerly known as the Marsden lode and the Peru mine, is in the NE¼ sec. 4, T. 27 N., R. 1 E. The deposits, found in a spring and opened by Stephen Marsden in March 1854, was operated as a lead mine until 1860, and as a zinc mine until 1883. It was reopened in 1907, but closed again in 1908. The New Jersey Zinc Co. reopened it in 1913 and operated on a large scale until March 1, 1927. The Black Jack mine was reopened in 1951 and operated until 1952. Descriptions of the mine during the early periods of operation can be obtained from the reports of Chamberlin (1882, p. 477–478), Bain (1905, p. 41–43), Cox (1914, p. 51–54), and Willman, Reynolds, and Herbert (1946).

This is one of the largest mines in the Wisconsin-Illinois-Iowa zinc-lead district, and it is reported to have produced nearly 2,000,000 tons of zinc and lead ore. The mine trends generally N. 40° W. and is in a typical northwestward-trending linear ore body, which has a well-developed east-pitch zone and a weak west-pitch zone. The west pitch contains considerably more iron sulfide than the east pitch, so it was not as extensively mined. The mine has a length of 4,500 feet, a width of 200 to 300 feet, and a thickness of more than 120 feet. The ore body occurs in all the Decorah and Galena strata from the top of the Prosser cherty member down to the Spechts Ferry. The mine is noted for its large open cavities filled with stalactitic forms of galena, sphalerite, and marcasite. Three small arcuate ore bodies, open to the west, that had east trends where found along the west border of the mine, slightly west of the west pitch of the main ore body. They appear to have been formed in folds that cross the main northwestward-trending trough. The main ore body may turn westward at the north end of the mine and widen, or it may continue northwestward along the general trend. Toward the south the valley of Smallpox Creek cuts the trend. The valley, deeply filled with clay, is probably cut below the main ore-bearing zone and separates the Black Jack ore body from the Pittsburg mine ore body to the southeast.

Amelia mine.—The mine is located in the SW¼ SW¼ sec. 34 T. 88 N., R. 1 E., about one mile east of the Black Jack mine (the ore body is shown, unnumbered, on plate 1). The ore body was found by drilling by Mr. Paul Herbert of Tri-State Zinc, Inc. The ore body was opened by a truck incline from the west in 1956 and was in production early in 1957.

The ore body trends northwest; is controlled by northwest-striking, west dipping pitches in the Decorah formation and Galena dolomite.

Bautsch mine (*pl. 1, no. 10*).—This mine (fig. 77), in the south-central part of sec. 10 and the north-central part of sec. 15, T. 27 N., R. 1 E., was opened in 1946 by Tri-State Zinc, Inc., and is still in operation (1957). After geologic structure studies by the U. S. Geological Survey the ore body was found at the location proposed by the Survey in 1944 by U. S. Bureau of Mines drilling (Zinner and Lincoln, 1946) in a cooperative venture with the U. S. Geological Survey and later with the Illinois State Geological Survey. The drilling showed an ore body of more than 2,000,000 tons of ore (Lyons, Heyl, Agnew, 1949, p. 106) which was about 3,200 feet long, 200 to 400 feet wide, and 40 to 130 feet thick, one of the largest ore bodies in this mining district. Later prospecting by Tri-State Zinc, Inc., has greatly enlarged the reserves, so that it is probably the largest ore body known in the district. A shaft 282 feet deep

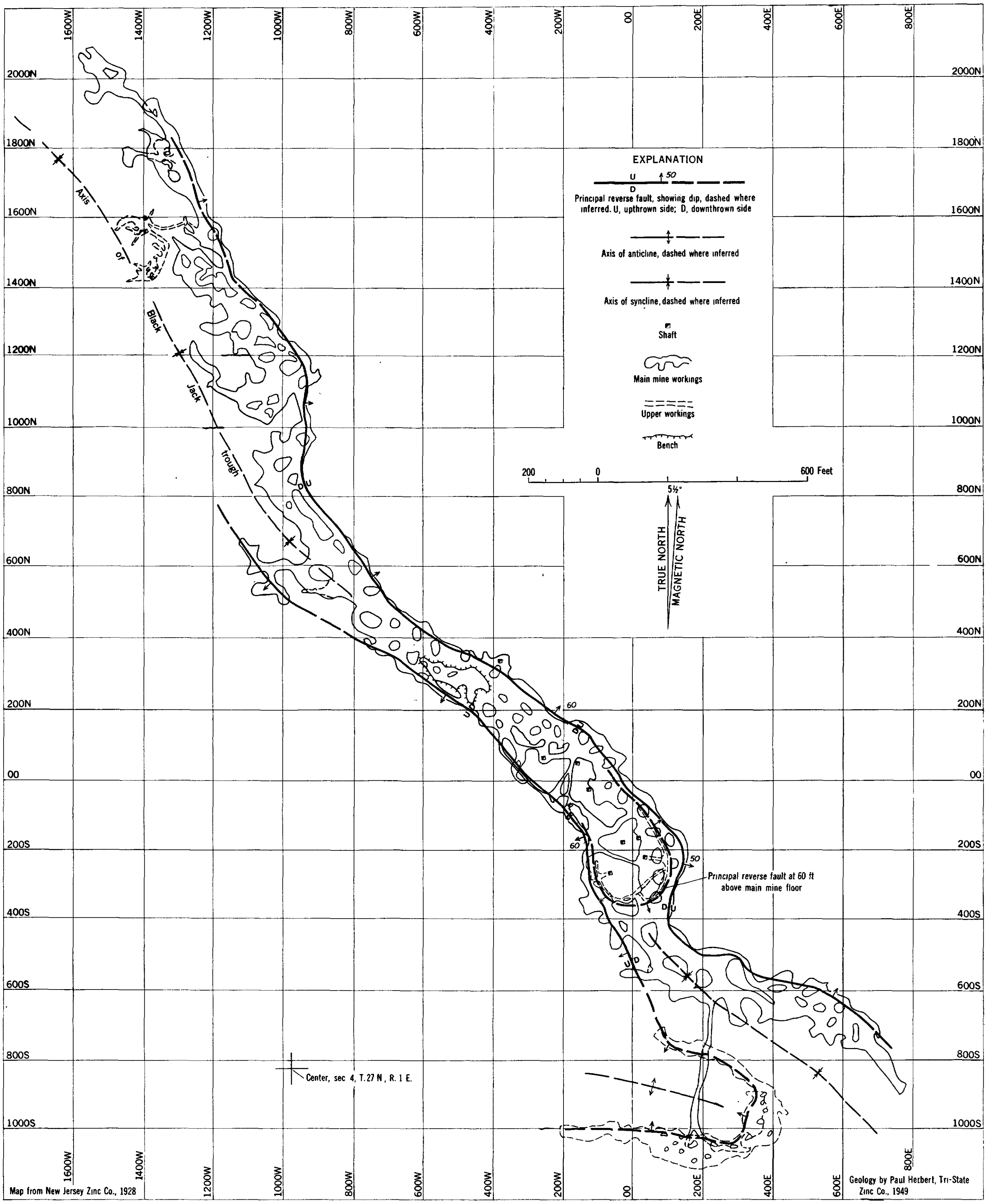
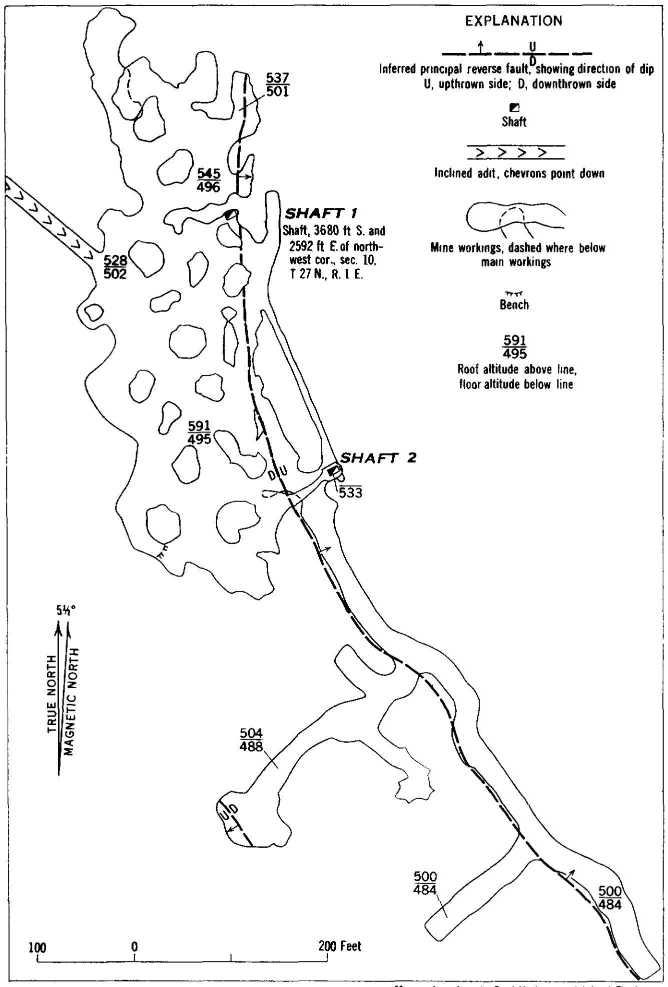


FIGURE 76.—Map of Marsden Black Jack mine.



Map and geology by Paul Herbert and John J Theiler, Tri-State Zinc Co., December 1949

FIGURE 77.—Map of Bautsch mine.

and a truck incline are at the north end of the mine, and a shaft 291 feet deep is near the middle of the ore body. Mining costs are unusually low and operations very successful. In 1949 about 1,500 gallons of water per minute was pumped from the mine.

The ore body, at the south end of the northwestward-trending linear Bautsch-Black Jack trough, is in both east- and west-dipping pitch zones and in the accompanying core ground. The ore is in all the beds from the McGregor member of the Platteville formation upward to about 70 feet above the base of the Galena dolomite. The ore is mainly in veins and replacements, with some breccia ore. The ore is high-grade and rich in both lead and zinc. The ore body becomes leaner at the north end, although the mineralized structure, not fully prospected, continues to the Gray ore body about 1,200 feet to the north. The south end of the ore body lies beneath a hill capped by Maquoketa shale and dolomite of Silurian age. Drilling to the south of this hill was shown a shallow structural trough, but ore was not found.

The ore body is notable not only for its large size, but also for the unusually large amount of solution thinning that has occurred. Notable thinning of all the strata including even those of the Galena dolomite had led to marked accentuation of the synclinal structure above the Platteville formation. Locally, solution sags, breccia and collapse breccia are abundant in the ore body.

Gray mine (*pl. 1, no. 11*).—The Gray ore-body (fig. 78), in the NW¼ sec. 10, T. 27 N., R. 1 E., lies just northwest of the Bautsch mine and is in the Bautsch-Black Jack trough. The ore body was discovered by New Jersey Zinc Co.'s drilling about 1926, and other parties in 1941–42 drilled a few holes. At the instigation of the U. S. Geological Survey, the U. S. Bureau of Mines (Zinner and Lincoln, 1946, Lyons, Heyl, Agnew, 1949, p. 106) began drilling in 1943 and by 1945 their joint program had developed an ore body about 1,300 feet long, 100 to 200 feet wide, and 25 to 50 feet thick. In 1944 Tri-State Zinc, Inc. opened the mine, and continued operations into 1949, when it was closed. Two shafts were sunk—one is at the north end of the mine, 195 feet deep; the other is in the south part, 278 feet deep. The ore body was estimated to contain 479,500 tons of ore that averages 4.3 percent zinc (Lincoln, 1945, p. 30). The mine pumped about 2,800 gallons of water per minute in 1945.

The mine was developed mainly in core ground and the ore consists in great part of solution breccia and replacement. The west pitch is barren. The ore is found in all beds from the upper part of the McGregor upward to about 35 feet into the Prosser member of the Galena dolomite. At the north end of the ore body the ore becomes too lean to mine. At the south end the ore ends abruptly, although the structure continues southward to the Bautsch mine and mineralized rock is present in places along it.

Royal Princess mine (*pl. 1, no. 12*).—The Royal Princess (fig. 75), the southernmost zinc mine in the district, is in the E½E½ sec. 28, T. 27 N., R. 1 E. The mine was operated from 1903 to about 1910 and had a large jig mill as part of the surface plant. It is not known whether the end of the ore body was reached by mining. Descriptions of the Royal Princess mine and of the nearby California Lead Diggings are available in the reports by Bain (1905, p. 40–41) and Cox (1914, p. 56–57).

This zinc and lead ore body is important because it is a gash-vein deposit along a mineralized joint in the Galena dolomite above the top of the Prosser cherty

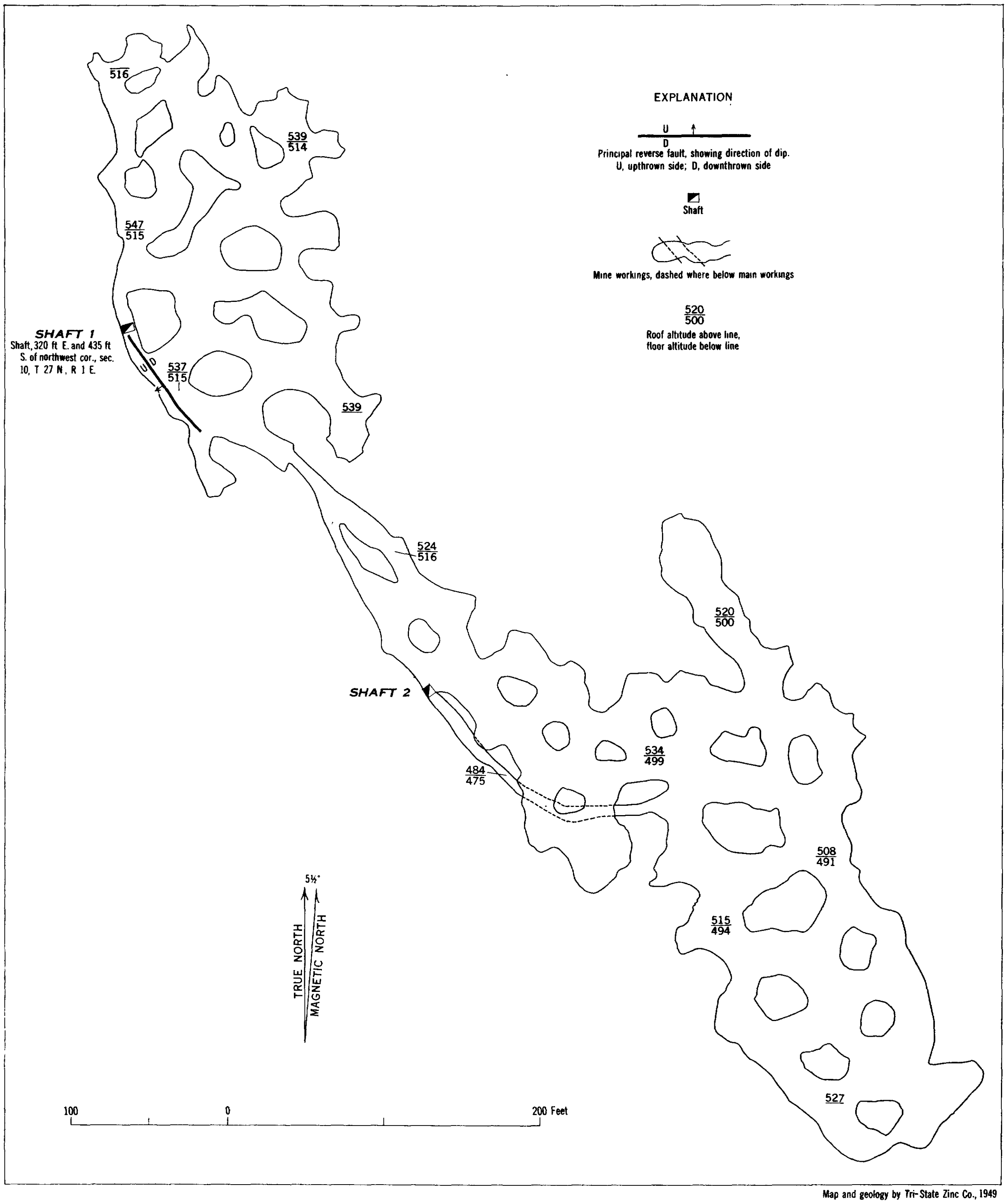


FIGURE 78.—Map of Gray mine.

member. It is overlain almost completely by the Maquoketa shale and dolomite of Silurian age. The ore body splits into two nearly parallel branches near its east end, about 2,350 feet from the tunnel mouth. The zinc ore was sphalerite and marcasite cementing a solution breccia. It was found only at the eastern end of the mine, where the stope was about 600 feet long, 40 to 50 feet wide, and 20 feet high (Willman, Reynolds, Herbert, 1946, p. 40). The strike of the controlling vertical joint, about N. 70° W. at the west end of the mine, swings gradually to nearly due east at the east end.

The U. S. Bureau of Mines core-drilled five inclined prospect holes in 1946 and 1947, seeking zinc ore in the lower part of the Prosser cherty member of the Galena dolomite, and in the Ion and Guttenberg members of the Decorah formation (Holt, 1948).

Oldenberg mine (pl. 1, no. 13).—The Oldenberg mine, in the center of the W½ sec. 1, T. 28 N., R. 1 W., was operated at intervals from about 1870 to 1907. Descriptions of this mine are given by Grant (1903, p. 73), and Willman, Reynolds, and Herbert (1946, p. 39–40).

The ore occurs in a breccia along an eastward-trending mineralized joint. The ore body, about 800 feet long, as much as 30 feet wide, and 40 feet thick, is in the beds near the top of the Prosser cherty member of the Galena dolomite.

Waters mine (pl. 1, no. 14).—This mine, just within the north edge of the city limits of Galena, in sec. 13, T. 28 N., R. 1 W., is well described by Bain 1905, p. 36–37). The ore body is in the lower part of the Stewartville massive member of the Galena dolomite, along a zinc-lead mineralized eastward-trending joint.

Little Corporal mine (pl. 1, no. 15).—The Little Corporal mine is in the NE¼SE¼ sec. 15, T. 28 N., R. 1 W. A good description of this mine was given by Bain (1905, p. 37–38).

The ore body is a typical east-trending gash-vein deposit, in which sphalerite rather than galena is the commonest mineral in the opening. The ore body is just above the top of the Prosser cherty member.

Merry Widow and Ten Strike mines (pl. 1, nos. 16 and 17).—These two mines, near the center of the east edge of sec. 22, T. 28 N., R. 1 W., were operated from about 1907 to 1917. Descriptions may be found in the reports by Cox (1914) and Willman, Reynolds, and Herbert (1946, p. 39–41).

The mines are controlled by the same N. 75° E. fracture zone, and are probably part of the same ore body. The lead and zinc ore is in veins in opposite-dipping pitches in the lower part of the Stewartville massive member and the upper part of the Prosser cherty member of the Galena dolomite. Cross fractures extending southeastward from the main joint contain principally zinc ore.

Betsy mine (pl. 1, no. 18).—This small mine (fig. 75) is at the extreme southwest end of the old West Galena Diggings, on the bluff of the Mississippi River near the center of sec. 27, T. 28 N., R. 1 W. At one time a small jig mill had been erected on the property. This mine produced lead and zinc carbonate ore between 1908 and 1913 (Willman, Reynolds, Herbert, 1946, p. 38).

The two shafts, approximately 520 feet apart, are at opposite ends of the mine. The ore body, in the Prosser member of the Galena dolomite, strikes due east. The mine is more than 60 feet wide in places, but was worked mainly by narrow drifts parallel to the southward-dipping pitch, which strikes along the south wall.

Buck Lead Range (pl. 1, no. 19).—The Buck Lead, a very old and important lead mine, is on a ridge in the NE¼SE¼ sec. 8, T. 28 N., R. 1 E. The Buck Lead Range is on Buck Hill in the middle of the Buck Hill diggings. The deposit was found prior to 1820 by Old Buck, a Fox and Sac Indian. It was worked by the Indians before 1823; when the first white settlers arrived in that year they took over and mined it for many years thereafter. This mine produced a very large tonnage of lead ore (Whitney, 1866, p. 203). It is probably the best known and one of the most important lead mines in the Galena area. Mining probably did not go below the ground-water level.

The main mineralized joints strike N. 88° W. and dip very steeply to the south. The ore body is of the gash-vein type, and has been traced for a length of 1,300 feet and a width of 20 to 30 feet.

Blewett mine (pl. 1, no. 20).—The Blewett mine (fig. 75) is in the southwest corner of the NW¼SW¼ sec. 9, T. 28 N., R. 1 E., near the east edge of the old and important Buck Hill lead diggings. The ore body was found in 1917 when the Galena Mining Co. drilled a line of holes across it. Additional drilling was done in 1918 by the Burr Mining Co. and later by the Frontier Mining Co., which commenced mining operations in March 1919 and continued until June 1920. The shaft is reported to be 230 feet deep, and from it about 400 to 900 gallons of water were pumped. About 75,000 tons of rock and zinc ore were hoisted (Willman, Reynolds, and Herbert, 1946, p. 33). In 1946 the U. S. Bureau of Mines extended the ore body by drilling (Holt, 1948). Considerable tonnages of ore remain in the mine at the north and west sides and beneath the present mine floor. Some ore may be present also to the south and east.

The ore body is apparently controlled by an outward-dipping arcuate pitch that is open to the west. A westward-dipping pitch strikes north along the west wall of the mine, so it is possible that the fractures form a complete ellipse. The zinc ore in the pitches and along the top flat is in veins, whereas that in the central core ground is disseminated and rich in iron. The drill records show that the ore body has a maximum thickness of about 45 feet, and averages between 20 and 30 feet. The ore body most consistently occurs in the blue beds of the Ion member and in the Guttenberg member of the Decorah formation. In the south part of the mine the workings extend downward into the Spechts Ferry member, but in the north part the mine floor is about 25 feet above the Guttenberg.

Appleton mine (pl. 1, no. 21).—The Appleton mine, in the SE¼SE¼ sec. 10, T. 28 N., R. 1 E., was in operation during 1908 and 1909, but was not profitable owing to the low-grade ore (the mill heads averaged 4 percent zinc) and the lack of sufficient development work by prospecting. The property was not prospected beyond one or two holes before mining commenced; mining was reportedly expensive and wasteful, owing to inexperienced operators. A 100-ton jig mill was erected and operated for some time. Perhaps as much as 20,000 tons of zinc ore was mined.

The ore is disseminated in the gray beds of the Decorah formation. The ore body seems to have a northerly trend, and the beds are said to dip toward the east.

Pilot Knob mine (pl. 1, no. 22).—This mine, on the top of the ridge just north of Pilot Knob, in the SW¼ NW¼ sec. 33, T. 28 N., R. 1 E., was operated for three months in 1914.

Two shafts mark the ends of the workings, which are roughly elliptical in plan. The shafts are 80 feet apart in an easterly direction. The west shaft is 112 feet deep and the east one is 96 feet deep. Stopes are 12 to 15 feet high. From the mine was pumped 300 to 400 gallons of water per minute. The enterprise was little more than a prospect.

The ore is sphalerite, fairly rich in iron sulfides, and contains a little galena. The ore fills cavities in a solution breccia, probably in the Prosser cherty member of the Galena dolomite.

Graham-Snyder mine (pl. 1, no. 23).—The Graham-Snyder ore body is in the southeast corner of section 25 and the northeast corner of sec. 36, T. 29 N., R. 1 W., about 4 miles north of Galena, Ill. The Eagle Picher Co. discovered the ore body by drilling in 1946, and mining was commenced by them the following year. The mine was closed in 1953, reopened in 1955 and still in operation in June 1957. A shaft was sunk 267 feet to the Spechts Ferry member of the Decorah formation—and was deepened 50 feet for a skip pocket. An escape shaft, near the north end of the mine, is 245 feet deep to the Spechts Ferry member. Pumping of water from the mine averaged 2,700 gallons per minute.

The ore body trends northwestward along a northwestward-trending structure that also contains the Graham-Ginte mine, several hundred feet to the southwest. The ore is localized in veins along an eastward-dipping pitch zone and in solution breccia in the core ground. The ore body is more than 1,500 feet long, as much as 250 feet wide, and 100 feet high. The ore, which is nearly lead-free zinc ore, occurs in all beds from the Quimbys Mill member of the Platteville formation upward into the Stewartville member of the Galena dolomite. Cross structures modify the major structure and the ore body.

The Snyder ore body to the north of the main mine was operated by means of a long haulage drift from the north end of the Graham-Snyder mine.

Hoosier mine (pl. 1, no. 24).—This ore body, in sec. 36, T. 29 N., R. 1 W., about a mile north of the Oldenberg mine (see p. 182), has been described by Cox (1914, p. 55–56). It is along a typical mineralized joint near the base of the Stewartville massive member of the Galena dolomite.

North Unity mine (pl. 1, no. 25).—The North Unity mine (fig. 75), operated by the Vinegar Hill Mining Co., is in the E½ of fractional sec. 16, T. 29 N., R. 1 E., just south of the Wisconsin-Illinois line. The deposit was discovered by drilling in 1913 and was mined at intervals from 1914 to 1948. A shaft was sunk 200 feet to the base of the Guttenberg member. Operations included a 100-ton jig mill. In the first period of profitable operation 285,000 tons of zinc-lead ore was mined,[35] and since then about 20,000 more tons of ore have been produced. The mine was reopened in May 1942 for robbing by Gill Brothers; they completed their operation in May 1943. The mine was reopened for further robbing and stoping by the Big Six Mining Co. in April 1945; this operation closed down in September 1947.

The ore body occurs in the Decorah formation and the lower beds of the Galena dolomite and forms a nearly-complete ellipse (fig. 75). At the east and west ends the pitches curve around and form arcuate noses, the fractures maintaining their outward dip from the central core ground area of the ore body. The ore body occurs on the flanks of a local third-order east-trending syncline that lies within a second-order northeast-trending syncline which contains the Northwestern, Vinegar Hill, South Unity, Hughlett and Gray, and North Unity mines.

Vinegar Hill mine (pl. 1, no. 26).—The Vinegar Hill mine (fig. 75) in the NE¼SW¼ sec. 21, T. 29 N., R. 1 E., is one of the older, important, rich zinc mines in Illinois. W. N. Smith and Mark Newman drilled the first ore in May 1905. They commenced operation in 1908 after forming the Vinegar Hill Mining Co., and the ore body was mined through the year 1914 at a large profit. The shaft is about 200 feet deep. About 360,000 tons of zinc-lead ore was mined during the period of operation.[36] About 600 to 700 gallons of

[35] Data furnished by the Vinegar Hill Zinc Co.
[36] Data furnished by the Vinegar Hill Zinc Co.

water per minute was pumped and used in a 100-ton jig mill. An earlier description of the mine was given by Cox (1914, p. 49–51).

The ore body has a total length of 1,200 feet, a width of 150 to 350 feet, and a thickness of as much as 100 feet. It is controlled by a set of well-developed arcuate pitches. The north limb at the north end has a north-dipping pitch and the southwest limb has a southeast-dipping pitch, which join and form a horseshoe nose at the northeast end of the mine. The ore is in rich veins along flats and pitches, and the ore body includes all the beds from the upper part of the Prosser cherty member of the Galena dolomite, downward to the top of the Spechts Ferry member at the base of the Decorah formation. The ore is high-grade sphalerite with small quantities of galena and only a very little iron sulfide.

Unity or South Unity mine (*pl. 1, no. 27*).—This mine (fig. 79), is in the SW¼NE¼, sec. 21, T. 29 N., R. 1 E., about three-eighths of a mile northeast of the Vinegar Hill mine. The ore was found by drilling in 1909, mining commenced in May 1910, and operations by the Vinegar Hill Mining Co. continued through the year 1912. The shaft is 140 feet deep, and the company operated a 100-ton gravity mill. Production has been an estimated 130,000 tons of ore. The ore before milling during the later period of operations averaged about 7.4 percent zinc. The mine was reopened in 1942 and was operated again in 1946 and 1947 by other companies.

The ore body consists of two parallel eastward-trending ore bodies, about 300 feet apart. The mine opening in the north ore run is about 800 feet long and 200 feet wide, whereas the south ore run is only 250 feet long and 60 feet wide. The stopes reach heights of 25 feet, in the Ion and Guttenberg members of the Decorah formation. The ore body is controlled by well-developed east-striking pitches, which dip to the north in the north ore run and to the south in the south ore run. The ore body is on the flanks of a well-developed eastward-trending syncline.

Drilling has shown lean ore to the west of the north ore body; however, the area west of the south limb is relatively unprospected (William, Reynolds, Herbert, 1946, p. 34).

Hughlett and Gray mine (*pl. 1, no. 28*).—The Hughlett and Gray mine is at the east end of the same ore body in which the South Unity mine is located, and was also operated profitably by the Vinegar Hill Mining Co. The ore body was discovered by drilling in 1919. Mining commenced in that year and continued until the end of 1921. The mine was reopened in February 1941 by Gill Brothers Mining Co., and additional stoping and robbing was continued until February 1943. The total production of the mine was about 350,000 tons of zinc-lead ore.[37]

The ore body is a continuation of the two east-trending parallel ore-runs of the south Unity mine, and has a typical eastward-trending arcuate form, open to the west. The limbs of the ore body are about 400 feet apart, and the shaft was sunk about 150 feet in the south limb to the base of the Guttenberg. The ore body is controlled by well-developed pitches that dip north in the north limb, south in the south limb, and join at the east nose with an eastward-dipping arcuate pitch. The ore body contains typical vein ore along pitches and flats, is in places quite rich, and contains considerable quantities of galena, and a very little chalcoprite. The ore body is 30 to 35 feet thick and the stopes extended from the base of the Guttenberg member of the Decorah formation up into the Prosser cherty member of the Galena dolomite.

Northwestern mine (*pl. 1, no. 29*).—The Northwestern ore deposit (Cox, 1914, p. 54–55, and Bain, 1905, p. 39–40) in the E½NW¼NW¼ sec. 22, T. 29 N., R. 1 E., was discovered in the winter of 1903–1904. In the spring of 1904 the Northwestern Lead-Zinc Co. sank a 92-foot shaft into the Guttenberg member of the Decorah formation at the east end of the north limb of the ore body. This shaft was abandoned in 1907, and about 200 feet to the south a new one was sunk 121 feet in depth. Mining continued with some interruptions until sometime after 1913. The property had a well-equipped jig mill, and the long life of the mine indicates a fairly successful operation. Production data are incomplete but suggest that between 100,000 and 150,000 tons of ore was mined.

The ore body has an arcuate form with two westward-striking limbs closing in a nose at the east. Mining extended 400 feet west along the north limb and 600 feet west along the south limb, and the nose of the arcuate ore body was mined out. The ore body has a typical outward-dipping arcuate pitch. The ore body is mostly in the blue beds of the Ion and in the Guttenberg member of the Decorah formation and is 10 to 15 feet thick. The ore occurs as veins in well-developed flats and in irregular fractures and small pitches, and is mainly sphalerite, with considerable galena and a relatively small amount of iron sulfides. Although the mine was developed below water level, there was some oxidation of the ore.

Birkbeck mine (*pl. 1, no. 30*).—This mine is in the NE¼ sec. 27, T. 29 N., R. 1 E. The ore body was explored in 1913 or 1914 by 25 holes drilled by the Frontier Mining Co. Later, some holes were drilled by the Council Hill Mining Co. In July 1915 the Wisconsin

[37] Data furnished by the Vinegar Hill Zinc Co.

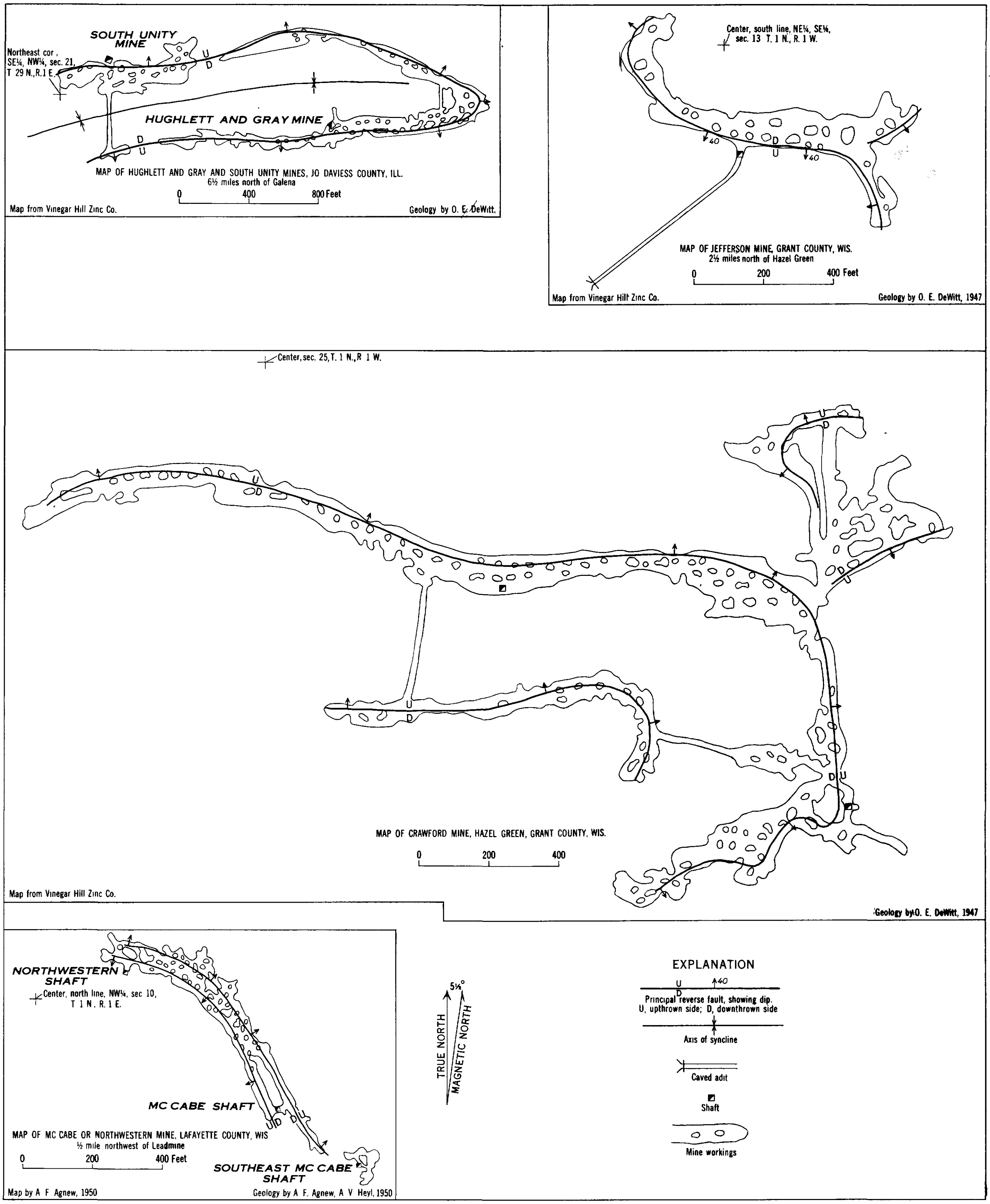


FIGURE 79.—Maps of Hughlett and Gray, South Unity, Jefferson, Crawford, and McCabe (or Northwestern) mines.

Zinc Co. did some drilling and in 1915–1916 sank the shaft to a depth of about 190 feet. A 150-ton jig mill was erected and shipments of concentrate commenced in August 1916, but mining was suddenly suspended in March 1917. The mine produced about 30,000 tons of ore, which, when concentrated by jigging, yielded 1,857 tons of zinc concentrates that averaged 26.85 percent zinc, 19.5 percent iron, and 0.35 percent lead (Willman, Reynolds and Herbert, 1946, p. 33). The grade of ore mined was low, probably averaged between 2 and 3 percent lead and zinc, as calculated from the above data. About 500 gallons per minute of water were pumped during mining.

The above prospect drilling revealed a northwest-trending ore body about 700 feet in length and 50 to 250 feet in width; the ore averaged 15 feet in thickness and had a maximum of 50 feet. The drill data indicates that a large tonnage of unmined ore remains northwest and southeast of the mine workings. The ore body has not been delimited by drilling in either direction (Willman, Reynolds, Herbert, 1946, p. 33).

The ore body may contain pitches parallel to its length along the northeast and northwest sides, dipping to the northeast and southwest respectively. The ore is included in the Prosser cherty member of the Galena dolomite downward into the McGregor member of the Platteville formation. The ore replaces the limestone and dolomite and cements rock breccia.

The mine was worked only in the immediate vicinity of the shaft and is an irregular stope about 300 feet long and 200 feet wide.

Graham-Ginte mine (formerly Bartel and Sherrill) (pl. 1, no. 31).—The Graham-Ginte mine (fig. 69) is one of the large important zinc mines in Illinois. It is near the center of fractional sec. 32, T. 29 N., R. 1 E. The initial mining was at the north part of the mine, where the tops of the main pitches cropped out. This work was done by the Bartel & Sherrill Mining Co. prior to 1915. Early that year, while lead and zinc mining operations were still in progress at the shallow Bartel & Sherrill mine in the top of the pitches, the Vinegar Hill Mining Co. drilled a line of holes at the north end of the ore body at right angles to the trend, discovering the deeper ore. The latter company commenced mining in 1916, sank a shaft at the north end of the ore body, and called it the Graham mine. This operation continued until 1920 when the plunge of the floor of the ore body at the south end forced the closing of the mine. In August 1943 the mine was pumped out by the Ginte Mining Co. and a shaft was sunk at the south end of the old Graham mine. Stoping continued to the south on the ore body, and also considerable tonnages were mined, that had remained in the central core ground and along the pitches of the old Graham mine. The mine produced about 350,000 tons of zinc-lead and lead ore to September 1945, and was closed February 1946.[38]

The geology of the mine is described in detail (p. 125) under the section on the details of the structures and textures of the ore bodies.

MINES IN WISCONSIN

HAZEL GREEN-SHULLSBURG SUBDISTRICT

The Hazel Green-Shullsburg subdistrict (pl. 1) has been the most important lead- and zinc-producing area of the mining district. At the south it joins the Galena subdistrict, and a southeast-trending zone of recently discovered zinc ore bodies and of sparse lead diggings connects it with the Scales Mound subdistrict in Illinois. A similar zone trends northeast toward Darlington, Wis. At the north edge, a continuous though somewhat more sparsely mineralized zone, joins the Hazel Green-Shullsburg subdistrict with the Meekers Grove-Jenkinsville subdistrict.

The stratigraphic sequence is similar to that observed elsewhere in the district, but some units change in thickness and lithology. The Spechts Ferry shale member of the Decorah formation, about 2 feet thick at Hazel Green, gradually thins to the east, and is only about 6 inches thick in the vicinity of Shullsburg. The Quimbys Mill member of the Platteville formation thickens eastward from about 8 feet at Hazel Green to about 15 feet of limestone at Shullsburg, and about 3 miles east of Shullsburg changes to dolomite. The Guttenberg member of the Decorah formation is about 12 feet thick; however, in mineralized areas where it has been dissolved and shalified, it is locally as thin as 6 feet. The blue and gray beds of the Ion member dolomite of the Decorah formation are well-defined useful markers. Throughout the subdistrict, alteration effects of solution and dolomitization and silicification in and near ore bodies are abundant in the upper part of the Platteville formation and the Guttenberg member of the Decorah formation. Solution structures, including tumbled breccias, are more abundant near Shullsburg then elsewhere in the subdistrict.

The subdistrict shows relatively intense deformation (pl. 5) similar to that farther south, but more intense than in the Meekers Grove-Jenkinsville to the north. The area is bounded on the north by the Meekers Grove anticline. Within the area the smaller folds trend toward the northwest, northeast, and east. The most important northwestward-trending folds controlling ore bodies (pl. 5) are the Kennedy syncline and the Frontier-Strawbridge syncline. Northeastward-trend-

[38] Data furnished by the Vinegar Hill Zinc Co.

ing folds are the Crawford-Martin syncline and a complex trough, containing the arcuate ore bodies, which extends northeastward through New Diggings. An important eastward-trending syncline, which contains the Champion and other linear ore bodies, is the Champion syncline, just south of New Diggings.

Most of the zinc ore bodies are of the arcuate and linear types, but a few elliptical and gash-vein ore bodies are in the subdistrict. Vein ore is most common in well-developed pitches and flats, many small deposits of lead ore occur along joints and in openings in the Prosser member of the Galena dolomite. Truly disseminated ore bodies are uncommon. In the northeastern part of the subdistrict barite is abundant in the veins, and this mineral is commonly accompanied by small quantities of chalcopyrite. In secs. 33 and 34, T. 2 N., R. 1 E. barite has been mined in two or three places. In the eastern part of the subdistrict mineable zinc deposits are found in the McGregor member of the Platteville formation. The Quimbys Mill member of this formation is probably ore-bearing in most of the larger pitch and flat ore bodies, but has only been mined or prospected in a few of them.

Tommy Dodd mine (*pl. 1, no. 1*).—The Tommy Dodd mine, in the northwest corner of the SW¼SE¼ sec. 13, T. 1 N., R. 1 W., is at about the center of the old South Lead Range which trends N. 35° E. and was last mined during 1870–1880. A shaft was sunk at least 50 feet by the Tommy Dodd Mining Co. about 1906. In the vicinity several drill holes were put down to the Spechts Ferry member of the Decorah formation, but no records are available. Ore is reported to have been struck in the holes at depth of about 50 feet and about 146 feet. The ore on the small mine dump is rich in solution breccia zinc and iron sulfides. The size of the mine dump indicates that only a small amount of stoping was done. No mill was built, and the miners apparently were unable to concentrate the ore by hand sorting because of its "brangle" nature and high iron content.

Jefferson mine (*pl. 1, no. 2*).—The Jefferson mine (fig. 79), in the SE¼ sec. 13, T. 1 N., R. 1 W., was opened in a gash-vein lead deposit that is eastward-trending. Mining for zinc ore began in July 1902, and by the summer of 1903 five shafts had been sunk, the deepest of which is 110 feet, and some zinc and lead ore was mined from brecciated rock. The mine was inactive by the end of 1903, but was later reopened and operated by the Kennedy brothers. Considerable galena was mined in 1909. The deeper pitch-and-flat ore body was found by drills operated by the Vinegar Hill Mining Co. in 1918. The mine was opened in 1919, and operations continued until June 20, 1920. The shaft was sunk 232 feet, to the base of the Guttenberg member. In order to lower the head of water for pumping, a 550-foot drainage adit was driven northeast from Scrabble Creek, and this adit intersected the shaft about 50 feet below its collar. Water was a serious problem during operation, and 2,200 gallons per minute were pumped. The mine was shut down in 1920 owing to the high pumping costs and low market values in that year. From 1918–20 the mine produced 153,577 tons of ore.[39] The Jefferson mine and the nearby Birkett, New Birkett and Byrnes mines were reopened in 1953 by the Eagle Picher Co. as their Birkett mine through a truck incline and a network of drifts. The access incline slopes westward from the surface at a point several hundred yards east of the New Birkett mine. The ore is hauled for processing to the Graham-Snyder mine mill in Illinois, and the mine was still in operation in June 1957.

The ore body has been mined for a length of about 1,000 feet and a width of 50 to 100 feet. Considerable drilled-out ore remains beyond the present workings at both ends of the mine. The stopes are 20 to 63 feet high and include all the beds from the lower part of the Prosser member of the Galena dolomite down to the base of the Guttenberg member of the Decorah formation. The ore body is controlled mainly by an east-striking pitch that dips south about 40 degrees. This pitch curves to the north at the west end and to the south at the east end, where it probably is a continuation of the west pitch of the Birkett mine to the southeast (pl. 5). In the short northeast-trending prong at the east end of the mine is a southeast-dipping pitch.

Hazel Green mine (*pl. 1, no. 3*).—Lead ore was mined from shallow workings during the nineteenth century on the Kennedy Lead Range which overlies the Hazel Green mine. The zinc ore deposit was found by test pitting along the old lead workings about 1902. The Hazel Green mine (pl. 21) was opened that year (Bain, 1906, p. 86–88) and operated until 1909.

The mine was reopened by the Hazel Green Mining Co. in September 1944, when pumping at the New Birkett mine to the east lowered the water table sufficiently to drain it also. The Hazel Green mine operated until April 1945 when the closing of the New Birkett mine increased the water flow to 800 gallons per minute at the Hazel Green mine and led to its abandonment. The ore averaged 6.5 percent zinc during this period of operation.

The details of the geology of this mine have been described on pages 128. The deposit is in the upper part of the Prosser member of the Galena formation and is a "middle-run deposit" similar to those described

[39] Data furnished by the Vinegar Hill Zinc Co.

by Willman, Reynolds, and Herbert (1946, p. 18) in Illinois.

Sphalerite ore, very rich in places, cements a solution breccia in the core ground between the main pitches along which some vein ore also occurs. In one place a large ore-lined solution cave was found. Only a very little galena accompanies the sphalerite, and iron sulfides are only locally abundant.

So far as is known, the beds of the Decorah formation have not been prospected beneath the present mine workings, even though a few drill holes penetrating these beds east of the mine showed some ore in the Decorah. The strong controlling reverse faults which cut into the mine floor suggest that a fracture system favorable for ore deposition is present in the deeper beds.

Honest Bob mine (pl. 1, no. 4).—The Honest Bob mine is in the center of the SE¼NE¼ sec. 25, T. 1 N., R. 1 W. It is an old lead mine operated by the Crawford Mining Co. from the middle of the nineteenth century until about 1904. Zinc ore was found at the water table by sinking a shaft 70 feet deep.

The ore is in the lower part of the Stewartville massive member of the Galena dolomite. The deposit is a typical solution breccia ore, probably in openings along N. 15° E. joints. The mine dump contains rich zinc ore.

Very near the Honest Bob shaft is the Phelps lead range, which trends about N. 15° E. Shafts were sunk 90 feet deep and connected with drifts 150 feet long in the "clay" openings (20 feet above the top of the Prosser member of the Galena dolomite). The galena occurs as a vein about an inch thick. Strong (1877, p. 706) stated, "Near these diggings, and about ten feet deeper, is an east and west sheet dipping to the north, carrying bunches of blende." It is not known whether this area was mined in the Prosser member of the Galena dolomite, but that zone appears to have considerable promise.

Scrabble Creek mine (pl. 1, no. 5).—The Scrabble Creek mine, 300 feet southeast of the Honest Bob mine, is near the center of the SE¼SE¼NE¼ sec. 25, T. 1 N., R. 1 W. The Scrabble Creek Mining Co. drilled 30 to 50 churn and diamond drill holes on the property. They reportedly struck good zinc and lead ore in the Ion dolomite member of the Decorah formation in many of these holes. A shaft was sunk in January 1909, and a solution breccia zinc deposit in gash-veins with an east trend was mined the following year in the Galena dolomite. It is thought that no deeper ore was mined; as the venture was reportedly speculative, deeper ore may not exist.

Madison mine (pl. 1, no. 6).—The Madison mine is a small zinc and lead mine in the NE¼NE¼SE¼ sec. 25, T. 1 N., R. 1 W. It was operated as a lead mine by the Crawford Mining Co. during the nineteenth century and mining continued to the end of 1901. Around 1900, it is reported that 500 tons of lead concentrates and considerable quantities of sphalerite and smithsonite were hoisted from this ore body. The shaft is 105 feet deep. About 550 gallons per minute of water were pumped. The ore body is of the gash-vein type, containing crystallized galena ("cog lead") and solution breccia zinc ore in joints and openings. Most of the mineralized joints in the area of the mine strike northeasterly or due east. The ore body was probably in the lower beds of the Stewartville massive member of the Galena formation.

The Crawford Mining Co. also operated the Klondyke, the Detroit, and the Lucky mines in the immediate vicinity, which are similar geologically.

Crawford mine (pl. 1, no 7.).—The Crawford deposit (fig. 79), in the SE¼ sec. 25, T. 1 N., R. 1 W., at the south edge of Hazel Green, was discovered by the Vinegar Hill Zinc Co. in February 1931. The shaft is about 200 feet deep to the Spechts Ferry shale member. The mine was operated by the Vinegar Hill Zinc Co. from 1932 until January 4, 1936, and probably produced about 500,000 tons of ore. The mining was done during a period of extremely low market prices in the early 1930's. About 1,000 gallons of water per minute was pumped, and the property had a 320-ton jig mill.

Overlying the deeper zinc-lead ore bodies lead ore was mined during the nineteenth century along eastward- and northeastward-trending joints and associated openings in the lower beds of the Stewartville member of the Galena dolomite (Percival, 1854, Hall and Whitney, 1862).

The ore is in two concentric horseshoe-shaped bodies with the open ends toward the west. The general trend of the deposit is about due west. The north limb of the outer arcuate ore run is 2,300 feet long and about 100 feet wide. The north limb of the inner arcuate ore run is about 900 feet long and 50 feet wide. Both north limbs of the ore body have well-developed north-dipping pitches, which at the east end turn sharply to the south. The controlling pitch of the south limb of the main outer arcuate ore run dips toward the southeast. An irregular prong of ore controlled by local pitches extends for 600 feet to the northeast of the main ore body.

The ore body borders a local east-trending basin within the larger northeastward-trending Crawford-Martin syncline (pl. 5). This larger syncline continues to the southwest, and is marked at the surface by lines of old lead pits. The ore is typical vein-sphalerite and some galena in well-developed pitches and flats. Considerable evidence of faulting of small displacements was seen along horizontal and inclined fractures (Behre, Scott, and Banfield, 1937, p. 795). The ore occurs mainly in the Ion and Guttenberg members of the Decorah formation. Maquoketa shale lies as a cap over much of the ore body.

Etna mine, and Appleby or Looney Level (pl. 1, nos. 8 and 28).—The Etna mine (pls. 5, 21, 108) and the older "Level" are in the SE¼SE¼ sec. 2 and the NE¼NE¼ sec. 11, T. 1 N., R. 1 E. In the 1850's the Looney Level (Percival, 1855, p. 56) was driven northwestward as an adit from the north bluff of Shullsburg Branch, and lead was mined along it. Later mining in the nineteenth century was done to the north along this trend in the Applyby and Cottingham ore bodies.

The Etna mine, which included the northwest parts of both the Applyby and Cottingham ore bodies, was operated from about 1902 to 1910 for zinc-lead ore by the Etna Mining Co. It was in two ore bodies in the Prosser member of the Galena dolomite and some of the last mining was done in the gray beds of the Decorah formation. The west ore body was mined through about 900 feet of narrow drifts along a general N. 37° W. trend. This ore body is reportedly controlled by northeast-dipping pitches. The east Etna ore body lies about 300 feet northeast of the north end of the west ore body, and was stoped irregularly. The Etna mine ore bodies lie within a well-defined syncline trending N. 37° W. The main shaft is 90 feet deep, and the others are 40 to 70 feet deep. The mine was rich and successful.

Further descriptions of this mine, from the earliest operations until 1905, are given by Percival (1855, p. 52), Whitney (1862, p. 295–296), and Bain (1906, p. 88).

Pittsburg-Benton mine (pl. 1, no. 9).—The Pittsburg-Benton mine (pl. 21) is in the SW¼SE¼ sec. 2, T. 1 N., R. 1 E. The mine, which was opened in the early 1900's and operated for a few years on a moderately large scale was again opened and operated from December 1944 to June 1946 by Carter and Meloy. Access to the mine workings was gained through a shaft 101 feet deep. The original shaft, which was badly caved and located 175 feet away, served to aid in ventilation. Probably about 7,000 tons of 5 percent zinc ore and 0.5 percent lead ore was mined from December 1944 to April 1946.

The earlier period of operation mined zinc-lead ore along both pitches, in a flat mine, and along a centrally located vertical fracture that strikes northwest. In 1945 low-grade ore was mined from the central core ground between the west pitch and the central vertical fracture.

The ore body is controlled by a double-pitch system, which shows reverse-fault movements and associated drag (see also p. 128). The pitches strike northwest, dip 35° to 40°, and have a steplike pattern. The straightness of this fracture system is very marked; the fracture walls are the straightest of any mine visited in the district. The pitches extend into the mine floor. At both ends of the mine the pitches continued into the walls.

The ore consists of sphalerite, smithsonite where oxidized, and less-abundant galena. It is present in veins along the pitches and in small associated flats, and as veinlets and breccia ore in the central core area, especially near a central vertical fracture.

The southeast face of the mine showed promise of possible extension.

The floor of the mine is about 35 feet above the Guttenberg member in the Galena formation. As many favorable beds are below the present floor, ore may exist below the mine workings. However, of the few holes drilled on this property in 1909 by the Wisconsin Zinc Co., only one recorded ore in the Decorah. So far as is known, no prospecting has been done below the Spechts Ferry shale member.

Corr and Crooked Six mines (pl. 1, no. 10).—The Corr and Crooked Six mines are in the same ore body, in the SE¼SW¼ sec. 2, T. 1 N., R. 1 E. The Corr lies northeast of the Crooked Six (pl. 5). The Corr mine was opened about 1908, and considerable galena was mined during that year. Above the main workings is an intricate network of old lead drifts mined at a much earlier date. The mine has four shafts about 100 feet deep and pump shaft that is 125 feet deep. The mine was operated until 1910. Zinc ore of a low grade, rich in iron sulfide, was mined at the southwest end.

The Crooked Six mine was operated by the Murray Mining Co. in 1911. The shaft bottomed in the Prosser cherty member of the Galena dolomite.

The ore body has a general N. 60° E. trend and has been mined for 1,200 feet at a width of 60 feet. In the Crooked Six mine a northwest-dipping pitch strikes northeasterly along the northwest mine wall. The ore body consists of flats and breccia areas of lead ore very rich in marcasite. The rock is badly oxidized and the roof in the Corr mine is considered unsafe. In both mines lean zinc ore in thin veins was mined along the west wall.

Possibly an 8-foot thick body of low grade zinc ore, rich in iron sulfide and accompanied by some galena, remains in the southwest part of the Corr mine. This zone has been mined out in the Crooked Six mine. No ore has been found below the Galena dolomite and thus the mines are in a "middle run" ore body (Willman, Reynolds, Herbert, 1946, p. 18).

McCabe mine (pl. 1, no. 11).—The McCabe mine (fig. 79) is about a mile northeast of Benton, in the SE¼SW¼ sec. 3, and the NE¼NW¼ sec. 10, T. 1 N., R. 1 E. The mine was opened and operated by the Wisconsin Zinc Co. during World War I, and was reopened and operated from 1941 to 1944 by companies organized by Harold Reinke, R. J. Teske, and Donald Peasley. In the last year of operation it was called the "Northwestern mine". They opened a second small mine in 1944 called the Southeast McCabe, which is in the same ore body in sec. 10, about 50 feet east of the southeast end of the McCabe mine.

The McCabe shaft is 101 feet deep; the Northwestern shaft, which is at the northwest end of the mine and north of the public road, is 61 feet deep; and the Southeast McCabe shaft is 76 feet deep. The stopes are between 12 and 15 feet high. A little water was pumped in the McCabe mine but none was encountered in the Southeast McCabe.

The production by the Wisconsin Zinc Co. is not known but is reported that the several companies from 1941 to 1944 produced a total of 11,500 tons of ore that averaged 7.5 percent zinc. The total production of the two mines is about 75,000 tons of ore and rock as estimated from the size of the stopes.

The McCabe ore body is of linear pattern and trends northwest, but at the northwest end the ore body turns westward and at the southeast end eastward. The ore body follows the axis of a narrow northwest-trending syncline (pl. 5) which can be traced in the workings, and by outcrops and drill holes for at least 1,000 feet to the northwest and southeast of the mine. The main controlling fractures of the ore body are northwest-striking reverse faults. These mineralized reverse faults form two parallel zones along the opposite mine walls, each dipping outward away from the central area of mine (fig. 79).

Most of the ore produced came from the Guttenberg member and so-called blue beds of the Ion member of the Decorah formation, but in the northwest part of the Northwestern shaft the ore was produced from the Quimbys Mill member of the Platteville formation. In the Southeast McCabe the ore is in the basal beds of the Galena dolomite. The ore is in veins of sphalerite with some galena, marcasite, and calcite in the reverse faults, along parted bedding planes, and in veinlets in fractured areas in the central core area of the mine between the fault (or pitch) zones. Very little breccia or disseminated ore was seen.

Kivlahan mine (pl. 1, no. 12).—This mine is in the SE¼NE¼NE¼ sec. 4, T. 1 N., R. 1 E. The Lucky Three Mining Co. sank a shaft 93 feet deep into the gray beds of the Decorah formation in 1900. About 500 feet of irregular drifting was done, mostly to the south of the shaft, and ore was reportedly left in the headings. About 20 holes were drilled south and southwest of the workings from 1908 to 1910, several of which showed zinc ore in the Ion member of the Decorah formation. A small tonnage of zinc ore was concentrated by hand jigging and shipped. A small volume of water had to be pumped from the mine. As the drill holes and the mine workings have not been accurately mapped, it is not known whether the mine has promise for future operations.

Smithsonite was reported in the shaft at a 65-foot depth. The dumps contain sphalerite ore in a breccia with considerable quantities of iron sulfides. The mine is at the eastern edge of a northwest-trending syncline.

McCann mine (pl. 1, no. 13).—The McCann is a small mine in the NE¼SE¼SE¼ sec. 4, T. 1 N., R. 1 E. The shaft is about 60 feet deep to the McGregor member. A very small tonnage of ore was mined. The ore is thin veins of sphalerite in the Quimbys Mill member of the Platteville formation.

New Calvert or "Soft" Calvert mine (pl. 1, no. 14).—This mine is in the SE¼SW¼ sec. 5, T. 1 N., R. 1 E. The Wisconsin Zinc Co. discovered the zinc-lead ore body by drilling on June 15, 1917. A shaft was sunk by the Baker and Meloy Mining Co. about 1940 to a depth of approximately 150 feet, but it was never completed. So far as is known, no ore was produced from the mine.

The ore body as drilled has a N. 70° W. trend, a length of 1,200 feet, and a width of 100 to 200 feet. Undoubtedly, considerable ore remains in this body; but it would probably be very expensive to mine, as a large amount of timbering would be needed to hold the soft, friable dolomite rock.

North Star or Ralph mine (pl. 1, no. 15).—This ore body, in the center of the E½E½ sec. 6, T. 1 N., R. 1 E., was discovered by the Vinegar Hill Zinc Co.'s drilling in 1943. The shaft was sunk to a depth of about 150 feet by the North Star Mining Co. in 1944. Operations commenced in October 1944 and continued until the early part of April 1946, when the mine was closed because of unsafe roof conditions. The ore body produced 15,000 tons of 6 percent zinc ore that contained very little lead. Some ore remains in the mine but additional drilling failed to indicate any large extensions. The mine had a distinct economic advantage in being about half a mile from the Vinegar Hill Zinc Co.'s custom mill; thus the haulage costs were very low.

The ore body has a general north ternd, a length of 420 feet, a width of 10 to 100 feet, and an average thickness of 13 feet. Vein ore occurs along pitches and flats in the Ion and Guttenberg members of the Decorah formation and the Quimbys Mill member of the Platteville formation.

Bull Moose and Middie mines (pl. 1, nos. 16, and 17).—The Bull Moose and Middie mines (fig. 80), in the SW¼ sec. 8, T. 1 N., R. 1. E., interconnected by drifts, consist of three closely spaced east-trending arcuate ore bodies. The southern and the middle ore bodies were found in drilling in 1912 by the Frontier Mining Co., which mined them from 1913 to 1921. The northern ore body was discovered in drilling by the Vinegar Hill Zinc Co. in 1926, and was mined from 1927 to 1929 by that company from the Middie shaft. Both mines are reported to have been very successful and profitable operations.

These important ore bodies lie in a local complex fold system within the larger northeast-trending Benton syncline (pl. 5). All three ore bodies are controlled by southward-dipping pitches. The main shaft of the Bull Moose mine is about 185 feet deep. The Middie mine shaft is about 200 feet deep. The ore in these mines extends through all the beds from the Prosser member of the Galena dolomite downward into the Guttenberg member of the Decorah formation. Vein zinc-lead ore, relatively rich in iron sulfides, occurs in well-developed pitches and flats. A little solution breccia ore occurs in the Prosser member. The ore is very high grade.

Some ore may remain between the Middie mine and Treganza mine to the northeast, a distance of 500 feet; but it is probably of low grade. It is reported that ore still remains in the extreme northwest heading of the Bull Moose mine.

Treganza, Frontier, and Calvert mines (pl. 1, nos. 18, 19, and 20).—These three separate ore bodies (fig. 80), which are connected by drifts, are in the NE¼ sec. 8, T. 1 N., R. 1 E. The Frontier mine was the oldest of these operations. Its ore body was found about 1905 in shallow shafts sunk by the Frontier Mining Co. About 1909 a shaft was sunk to about 110 feet, and mining was begun on a large scale; the mine operated continuously until about 1917. The Calvert deposit was discovered in drilling by the Vinegar Hill Mining Co. in 1908. In 1909 a shaft about 120 feet deep was sunk, and the mine was operated by that company until July 1910. Later the Frontier Mining Co. drifted to the Calvert deposit from the southeast and continued mining in it until about 1917. The Frontier Mining Co. drilled out the West Calvert ore body on the Calvert property, west of the Frontier mine, and followed it by mining southward to a point under State Highway 11. In 1911 the Burr Mining Co. drilled the extension of this ore body to the south and west. They sank a shaft to a depth of about 160 feet, and mined that part of the ore body and its westward continuation as the Treganza mine. Large quantities of water were pumped to drain the three mines.

The Frontier mine made a large profit for its owners and was considered one of the best zinc ore bodies in the district. The Calvert mine, while operated by the Vinegar Hill Mining Co. from September 1909 to July 1910, produced 45,000 tons of ore that averaged 7.5 percent zinc and had a low iron sulfide content.[40] Not a great deal of drilled-out ore remains, and the area in the immediate vicinity has been pretty thoroughly prospected by drilling. However, the mines have not been robbed and probably considerable ore may remain in the mines, and the possible presence of Quimbys Mill ore has not been tested.

The three ore bodies are at the intersection of the northwest-trending Frontier-Strawbridge syncline and the northeast-trending Benton syncline (pl. 5).

The Frontier ore body, which lies within a local elliptical, northwest-trending basin in the larger syncline, is a complete ellipse, controlled by an outward-dipping pitch that swings completely around the border of the ore body. The pitch is accompanied in the footwall area by a small elliptical drag syncline; this completely encloses the central core area whose structure is a low elliptical dome. Nearly all of the central core area contained ore of a mineable grade.

The Calvert ore body, about 150 feet to the northwest, is slightly larger but otherwise is structurally similar. The northwest end of the ore body was not completely mined.

The west Calvert or Treganza ore body is apparently the south limb of an east-trending arcuate zinc ore body, controlled by a well-developed southward-dipping pitch zone in the large northeast-trending Benton syncline that contains the Bull Moose and Middie mines to the southwest. The Treganza ore body becomes lean at the western end and probably connects with the northernmost of the three Bull Moose-Middie ore bodies to the southwest.

The ore of these mines is high-grade veins of sphalerite in well-developed pitches and flats. In the Frontier mine the ore occurs in all the beds from the Prosser member of the Galena dolomite down to the Spechts Ferry member of the Decorah formation. In the Calvert and Treganza mines most of the ore apparently does not extend below the gray beds of the Decorah formation.

Hird No. 1 mine (pl. 1, no. 21).—The Hird No. 1 mine (fig. 80) is in the SE¼SW¼SE¼ sec. 8, T. 1 N., R. 1 E. The zinc-lead ore body was found by the Frontier Mining Co., about 1913, and the mine was opened in

[40] Data furnished by the Vinegar Hill Zinc Co.

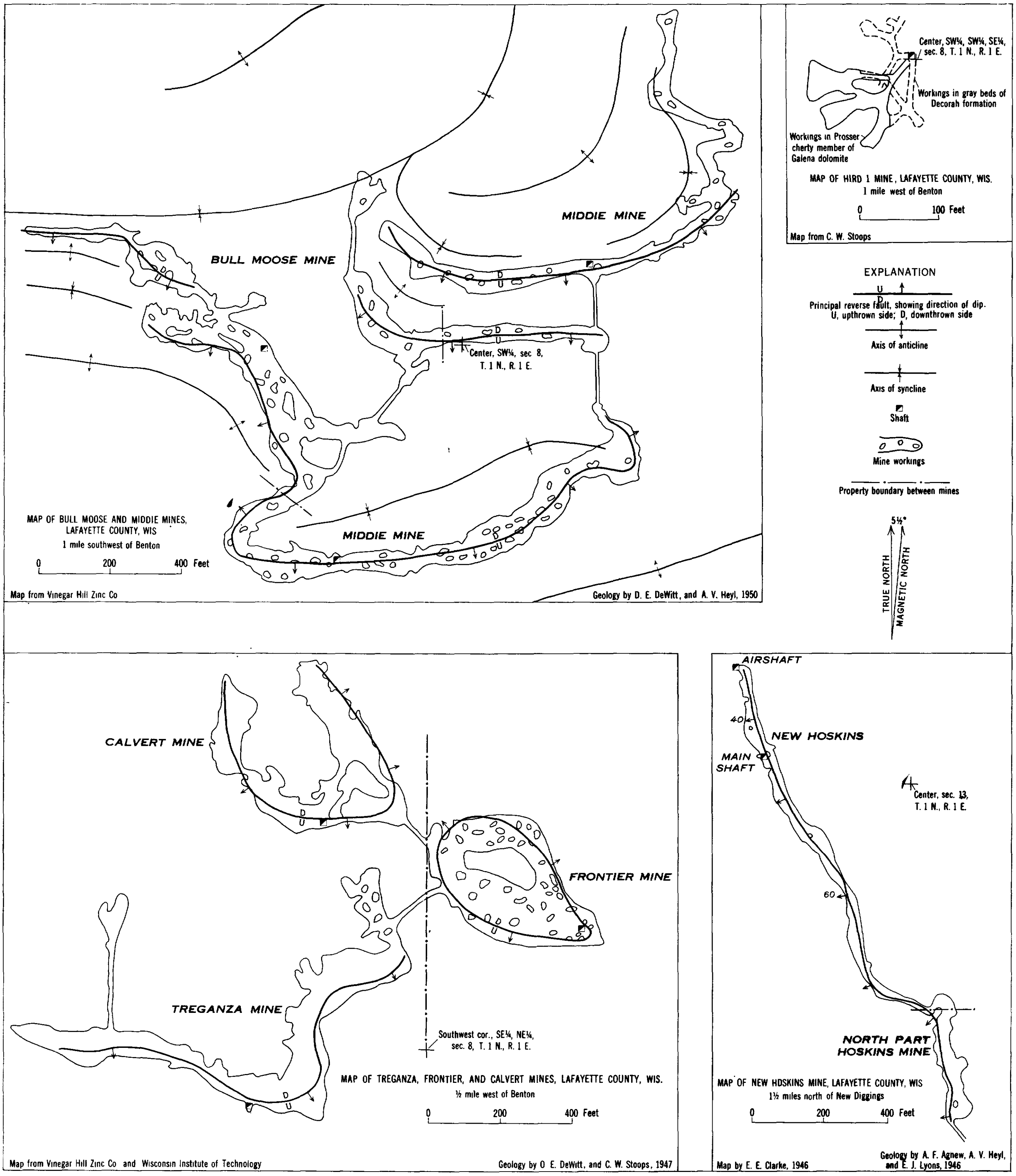


FIGURE 80.—Maps of Bull Moose, Middie, Treganza, Frontier, Calve rt, Hird No. 1, and New Hoskins mines.

1914 and produced ore in 1915. The ore is said to have been too low grade to be profitable, and the mine was closed when several men were suffocated by carbon dioxide. Operations had not continued far enough to determine the nature of the ore body and its controlling fractures.

The production from this mine is not known, but it was probably quite small. The thin-vein and breccia nature of the ore probably made it not too amenable to jigging and was likely a factor in closing the mine. Drilling to the south and to the northwest reportedly encountered ore.

The ore occurs in thin veins containing sphalerite and considerable galena, in scattered replacement crystals and also in solution breccia. Abundant marcasite coated the walls of cavities.

Century mine (*pl. 1, no. 22*).—The Century mine, in the SW¼SE¼SW¼ sec. 9, T. 1 N., R. 1 E., was first operated in April 1900 by J. V. Swift and Co. Some smithsonite and lead ore that occurs in flats and pitches was extracted that year from a depth of 45 feet. In 1906 the shaft was 145 feet deep, in the gray beds of the Decorah formation. The shaft was later deepened to 157 feet, to the Spechts Ferry member. The deeper workings consist of a long drift north from the shaft and a drift east of the shaft for 100 feet. At its east end the latter drift cut a N. 30° E. pitch that dips to the southeast and is reported to have contained sphalerite ore. Seven holes were drilled on the property, one of which struck sphalerite ore southeast from the shaft on strike with this pitch. The mine was abandoned shortly thereafter, probably because of insufficient ore. The ore is in breccia and contains abundant marcasite. The similarity to the core-ground ore of the nearby Martin mine (p. 121) makes this ore body potentially favorable for further prospecting.

Kearns mine (*pl. 1, no. 23*).—This mine, in the northwest corner of the SW¼NE¼ sec. 9, T. 1 N., R. 1 E., was opened by the Kearns Mining Co. in 1910 and was operated at intervals until 1918. The several shafts are between 50 and 60 feet deep. A small tonnage of ore was produced; and very little pumping was necessary.

The ore is in the Prosser member of the Galena dolomite, and consists of breccia and vein sphalerite ore along pitches, but in the upper stopes smithsonite was mined. The ore body appears to have been controlled by an arcuate pitch fracture, the open ends of which point north. The small stopes and narrow drifts closely follow these pitches for a few hundred feet. Drill holes did not indicate the presence of deeper ore, but examinations of the mine during the period of operation suggested that the ore-bearing pitches continue below the floors of the stopes.

Oregon or Milner mine (*pl. 1, no. 24*).—(Ball and Smith, 1901). This small zinc carbonate mine is in the center of the NE¼ sec. 9, T. 1 N., R. 1 E. The property was operated before 1901 by Pease, and in 1942 by R. J. Teske. Smithsonite ore was mined from the Prosser member of the Galena dolomite, although the shaft, which is 81 feet deep, penetrated the gray beds of the Decorah formation. The ore is said to have been found in a vein below well-defined east-trending fractures. Owing to sparcity of ore, considerable money was lost in the venture.

Quinlan diggings (*Lea and Swift's Bone diggings*) (*pl. 1, no. 25*).—These shallow zinc mines extend over a large area in the NE¼NE¼ sec. 9, T. 1 N., R. 1 E. Most of the mining was done prior to 1911 for galena, smithsonite, and sphalerite. In 1906 the Buchan Mining Co. was mining a flat vein of zinc ore said to be 22 inches thick, in the Quimbys Mill member of the Platteville formation, at a depth of 20 feet. Pumping of a small amount of water was necesary, as the ore body lay in the valley flat below water level.

The ore body is roughly Y-shaped. The N. 55° W. prong and the southeast projection together are 1,000 feet long and 100 feet wide. The northeast prong extends for 600 feet N. 45° E. and is 150 feet wide. The primary ore is mostly rich vein sphalerite, associated with only a little galena and iron sulfide, but the iron sulfide increases slightly at the southeast end, and markedly at the northwest end of the northwest prong.

Coltman mine (*pl. 1, no. 26*).—This deposit, near the center of the S½ sec. 10, T. 1 N., R. 1 E., was discovered in 1879, and was mined for zinc and lead until about 1906. It was worked through an adit driven from the west into the upper stopes, and through a shaft sunk from the top of the ridge to the base of the Quimbys Mill member of the Platteville formation. Considerable tonnages of smithsonite and a little galena were mined before 1895. A small tonnage of sphalerite was mined from about 1895 to 1906; and a small jig mill was erected about 1903. Pumping was necessary to drain the lower levels.

The Coltman mine is in the northwest part of an originally elliptical ore body now cut by the Galena River; the same ore body has also been mined in the Swift and Rooney mine at its southeast end (pl. 5). The Coltman part of the ore body is horseshoe-shaped, open toward the southeast. Outward-dipping pitches swing around the horseshoe. Zinc ore occurs in small veins along the pitches and flats and has been altered to smithsonite in the upper levels. Most of the smithsonite was mined in the gray beds of the Decorah formation about 20 feet above the Spechts Ferry member, and sphalerite was mined immediately below the smithsonite level. The ore is low in iron sulfide. Drilling in the McGregor member of the Platteville formation beneath the Quimbys Mill member showed pyrite and marcasite.

Swift and Rooney mine (pl. 1, no. 27).—(Dugdale, 1900, p. 36–37). The Swift and Rooney mine (pl. 5), in the SE¼SE¼ sec. 10, T. 1 N., R. 1 E., is one of the oldest zinc mines in the district. The deposit was discovered in 1861 and worked continuously from that time until at least 1910. The first zinc sulfide ore smelted in the district came from this mine. The mine was worked through two adits extending southeastward from the east bank of the Galena River. The floors of the adits were in the blue beds of the Decorah formation.

The mine produced an estimated 1,000 tons of high-grade hand-cobbed lead ore, and 2,500 to 3,000 tons of zinc concentrate. No pumping was necessary as the water level was below the mine floor. The mine is supposedly worked out.

The ore body has a general S. 70° E. trend and is arcuate in shape with the open end toward the northwest. In places the ore body is controlled by five parallel arcuate pitches, all dipping from the center of the arc outward at 45 degrees. The ore body was worked for galena, smithsonite, and sphalerite. The ore occurs as typical well-developed veins in pitches and flats, the main flat worked being in the blue beds of the Decorah formation. The stopes followed the pitches upward for 70 feet above the blue beds, into the Prosser cherty member of the Galena dolomite. The pitches converge upward, and at their intersection with the top flat form an ellipse about 12 feet across. This top flat is reported to have contained a vein of ore 2 feet thick. The pitches dip about 30 degrees near the top, and step down along three or four subsidiary ore-bearing flats. Galena occurs in larger quantities in the higher beds, where it is associated with smithsonite. The zinc ore is lean in marcasite and pyrite and of a good grade.

Ewing and Cook mine (pl. 1, no. 29).—The Ewing and Cook ore body, in the NE¼NW¼ sec. 12, T. 1 N., R. 1 E., was discovered in drilling by the Vinegar Hill Zinc Co. about 1941. The shaft, 100 feet deep to the gray beds of the Decorah formation, was sunk in 1942, and the mine was operated for a short time in June of that year. It was reopened in July 1945 and operated on a small scale by Ewing and Cook until July 1949.

This small, narrow ore body was mined mainly along northwestward-trending vertical fractures. Galena, smithsonite, and sphalerite occur as vein and braccia ore in and along these fractures. The galena and smithsonite are more abundant in the oxidized upper part of the stopes. Barite is abundant in all parts of the mine. The ore, which contains considerable galena, is reported to have averaged 4 percent zinc and 2.5 percent lead. It is one of the few mines from which smithsonite was shipped in recent years.

Weiskircher mine (pl. 1, no. 30).—The Weiskircher mine, in the NW¼SE¼SW¼ sec. 12, T. 1 N., R. 1 E., consists of two adits that strike S. 80° W. into the west bank of Shullsburg Branch. This old mine was opened before 1900 and last worked about 1907. A shaft was sunk about 400 feet southwest of the adits. The mine was reopened in July 1938, and mining was resumed for a very short time. The Weiskircher adits are in the blue beds of the Decorah formation. Both waste dumps contain considerable vein sphabute ore, rich in marcasite, and having considerable barite. The ore body is localized along a north-dipping pitch that strikes east along the north limb of a well-defined syncline. The prospect has potentially some low-grade zinc ore.

Imperial, Hoover, or Iowa mine (pl. 1, no. 31).—This mine (fig. 81), in the SE¼NE¼ and the NE¼SE¼ sec. 12, T. 1 N., R. 1 E., was originally operated in 1919–20 by the Iowa Mining Co. through a shaft 104 feet deep. After some stoping along nearby fractures, a drift was driven north for 120 feet to an east-trending zinc-lead ore body. In 1930 a shaft, the Hoover, was sunk in the southeast end of the arcuate part of the ore body by the Baker and Meloy Mining Co., and the mine was robbed, and probably some floor was taken up. In the spring of that year another shaft, the Imperial, 127 feet deep, was put down by this company 300 feet to the north, at the site of some drill holes that had located an extension of the ore body. This area was then mined. The Imperial part of the mine was reopened in 1941 and worked until September 1942 by the Hilltop Mining Co.

The earlier production from this property is not known, but the Hill Top Mining Co. produced about 11,400 tons of 13.5 percent zinc.

The older part of the mine produced good vein ore fairly rich in marcasite and pyrite from the Ion member of the Decorah formation and the Prosser cherty member of the Galena dolomite. The Imperial part of the mine contains good vein ore in a thick flat at the base of the Quimbys Mill member of the Platteville formation. The north-trending part of the Imperial workings has ore in veins along an east-dipping pitch and in the brecciated Quimbys Mill member. Ore was mined also from the Decorah formation and Galena dolomite above the ore in the Quimbys Mill. Particularly good vein zinc and lead ore, accompanied by abundant barite, was found in the Guttenberg member.

Old Cottingham mine (pl. 1, no. 32).—The zinc-lead ore body of the Old Cottingham mine, near the center

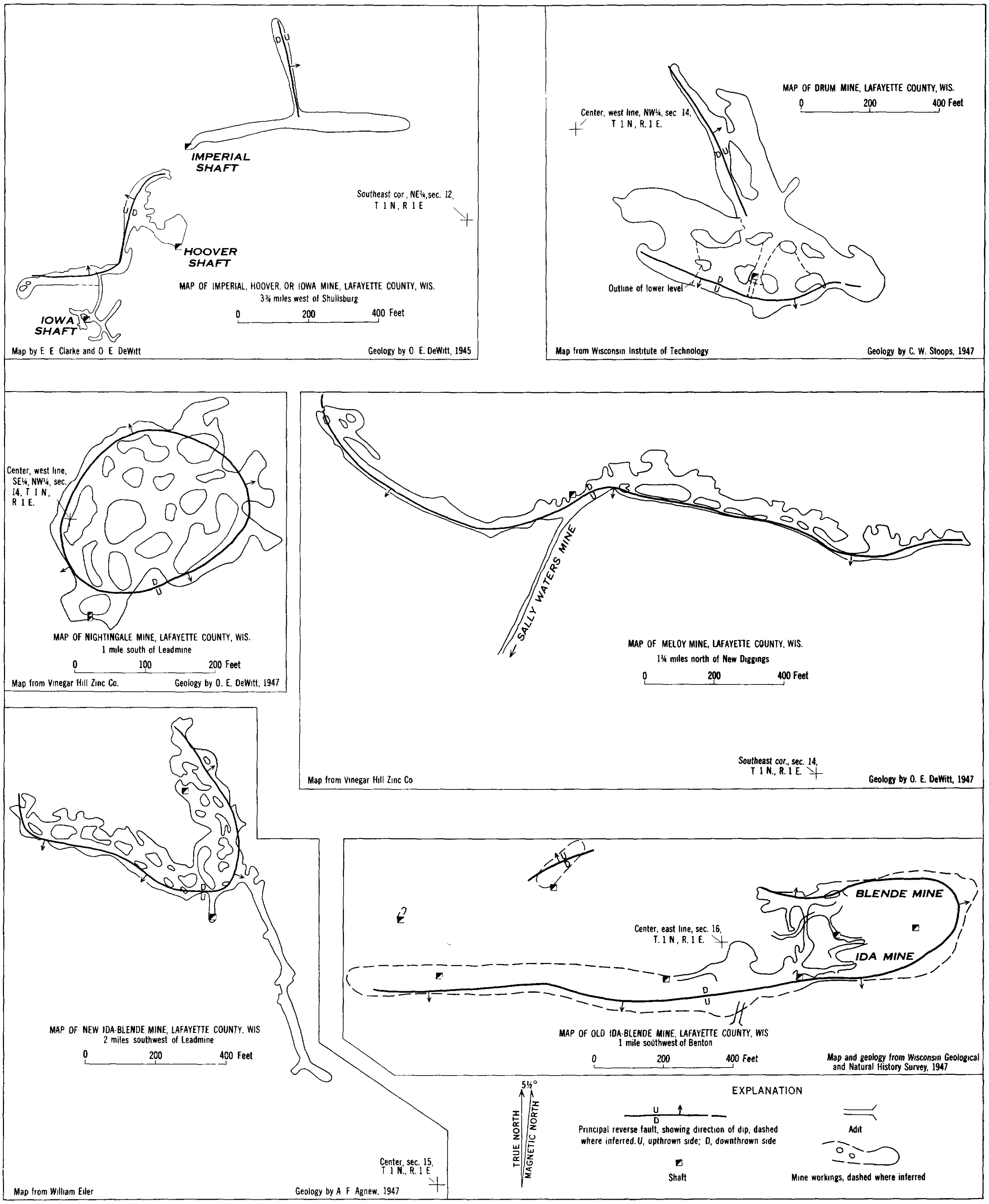


FIGURE 81.—Map of the Imperial (or Hoover, or Iowa) Meloy, Drum, Nightingale, New Ida Blende, and Old Ida-Blende mines.

of the SW¼NE¼ sec. 13, T. 1 N., R. 1 E., was found by the Fox Mining Co.'s drilling in 1944. A shaft was sunk during the latter part of 1944, and operations commenced in January 1945. This small mine operated until December 1945, when it was abandoned because of the narrowing of the ore run and the discovery of the much richer New Cottingham ore body nearby. An estimated 6,500 tons of ore was shipped that averaged 7 percent zinc and 0.7 percent lead.

The ore in the Old Cottingham mine occurs in the Prosser cherty member of the Galena dolomite in solution breccia along vertical crevices and is a gash-vein zinc deposit. The deposit was mined for 50 feet south of the shaft to a width of 20 feet, and then 100 feet east, where the ore body narrowed to 10 feet. The ore is an unusually light-yellow sphalerite, very low in iron sulfide.

New Cottingham mine (pl. 1, no. 33).—Operation of the New Cottingham mine, in the SE¼SE¼NW¼ sec. 13, T. 1 N., R. 1 E., was begun by the Fox Mining Co. in January 1946, and continued until March 1947 in rich zinc-lead. The Cottingham Mining Co. reopened the mine and shipped lean ore in April and May 1949. The ore body trends generally N. 15° W., and is somewhat sinuous (pl. 5). In April 1946 it had been mined about 300 feet north of the shaft and was connected at the south end with the New Hoskins mine. Probably the mine will eventually be connected to the Little Minnie mine to the north, as they are parts of the same ore body.

The New Cottingham mine is estimated to have produced 6,000 tons of ore that averaged 6 percent zinc and 3.5 percent lead. Several carloads of galena were hand sorted and shipped separately; thus the ore actually averages much more in lead than 3.5 percent.

The ore body occurs in the lower gray and blue beds of the Decorah formation and consists of a thick vein in the rich top flat 20 feet wide and a thin west-dipping pitch along the west wall. The ore body averaged 12 feet thick and is unusually rich in galena and vein sphalerite. Abundant coarsely crystallized calcite, as well as a little chalcopyrite and a trace of millerite, is found with the ore. A vug in a vein, large enough for a man to crawl in for about 200 feet, was lined with large calcite crystals and crystals of galena as much as a foot across.

Little Minnie mine (pl. 1, no. 34).—This small mine, in the NE¼SE¼NW¼ sec. 13, T. 1 N., R. 1 E., was discovered by the Empress Mining Co. in drill holes about 1907. Operations commenced about 1909 by the Minnie Mining Co. and continued until the latter part of 1911. The shaft is 125 feet deep. The property was not a very successful venture, owing to the small and low-grade ore body. A small jig mill operated 1 or 2 days a week.

The ore body has a general N. 10° E. trend and was mined 500 feet north from the shaft and about 20 feet toward the south. The ore is a flat of sphalerite and galena, overlain with some leaner ore richer in iron sulfide. The flat ranges from 16 to 50 feet wide, and is along the boundary between the blue and the gray beds of the Decorah formation. The stopes are only 6 feet high.

Empress mine (pl. 1, no. 35).—The Empress ore body, in the SW¼NW¼ sec. 13, T. 1 N., R. 1 E., was discovered in 1891, and was mined successfully by the Empress Lead and Zinc Co. until about 1906. From May 1891 to January 31, 1900, the mine produced 3,462 tons of hand-cobbed zinc concentrate and 435 tons of lead concentrate (Bain 1906).

An open cut was mined for smithsonite before 1900 a short distance west of the Empress mine. The open cut is probably controlled by the same fracture as the mine. The Empress ore body is controlled by two parallel, east-striking pitches that dip north and south, and is a typical east-trending linear ore body. Ore was mined from Prosser cherty member down to the Spechts Ferry member of the Decorah formation. The mine has been well-described and illustrated by Bain (1906, p. 85–86).

New Hoskins mine (pl. 1, no. 36).—This mine (fig. 80) is near the center of sec. 13, T. 1 N., R. 1 E., and extends northwestward from the north end of the North Hoskins ore body of the Hoskins-Fields mine.

The New Hoskins ore body was discovered by the Baker and Meloy Mining Co. in 1944, by drilling on a few thin galena-filled fractures discovered in a brook several hundred feet northwestward of the North Hoskins ore body. The New Hoskins mine was opened by Baker and Meloy in September 1944, and operated by them until April 1946, when the mine was closed because the ore was exhausted. The main shaft of the mine is about 100 feet south of the small brook and is 40 feet deep into the Guttenberg.

This mine produced an estimated 15,000 tons of zinc-lead ore that contained 8 percent zinc and 4 percent lead. In addition several carloads of hand-sorted lead concentrate were shipped indicating that the ore averaged about 6 percent lead.

The New Hoskins ore body trends northwestward and is controlled by a mineralized weak reverse fault that strikes parallel to the ore body, dips southwestward, has a displacement of about 3 feet, and is mainly in the Ion member of the Decorah formation. A small parallel drag syncline follows the fault in its footwall side, and a low northward-trending anticline follows the hanging wall side (pl. 5). These small folds and the ore body cross northward over larger east-trending folds: (1) an anticline at the south end and (2) a syncline in the valley at the north end of the mine.

The top flat in the New Hoskins mine contains a 2-foot thick vein of high-grade zinc-lead ore. It is at the top of the Decorah formation and contains large vugs lined with giant crystals (as much as 2 feet across) of galena (fig. 55) and calcite, associated with crystallized sphalerite and a little chalcopyrite.

The Hoskins-Fields mine or Hoskins mine (pl. 1, no. 37).—The Hoskins-Fields mine (pl. 12) is in the central part of S½ sec. 13, T. 1 N., R. 1 E. The North Hoskins, a north-trending ore body, was mined from the Hoskins-Fields mine by a drift several hundred feet long.

The Hoskins zinc-lead ore body was discovered in about 1916 by the New Jersey Zinc Co.'s drilling. Owing to the northeasterly trend of an overlying lead range, the presence of some ore holes in the North Hoskins ore body, and the difficulty of recognizing the pale-colored sphalerite in the drill hole samples, this deposit was at first interpreted as a lean northeast-trending ore body. A short time later, when the accurate pattern of the ore body had been determined, the Vinegar Hill Mining Co. drilled out the part of the ore body on the Fields property to the west. The New Jersey Zinc Co. commenced operations at the Hoskins in 1917 by sinking a shaft 163 feet to the Spechts Ferry member of the Decorah formation. The mine was one of the richest in the district, and was operated by the New Jersey Zinc Co. until January 12, 1926. In 1919 a drift was driven to the east, and the smaller East Hoskins ore body on the Booty property was mined. In 1920 an 800-foot drift was driven to the north, and the North Hoskins ore body was mined. The Vinegar Hill Mining Co. commenced operations on the Fields property in the early spring of 1920 by sinking a shaft 153 feet to the Spechts Ferry member. Mining operations continued on the Fields property until May 19, 1924. From March 1943 to June 1944 the Hoskins-Fields mine was reopened by the Baker Meloy Mining Co. for robbing, and from 1943 to about 1948 the old jig tailings were reworked by flotation in a mill operated by the Chestnut Ridge Mining Co.

The Hoskins-Fields mine (including the Hoskins-Fields, North Hoskins, and East Hoskins ore bodies) produced approximately 700,000 tons of high-grade zinc-lead ore, several shipments of which assayed 13 percent zinc and 2.5 percent lead, and in addition hand-sorted lead concentrates were shipped.[41] A considerable quantity of water was pumped to keep the mine drained.

The geology of the Hoskins-Fields mine has been described in detail (p. 119–120, pl. 12).

The known ore in the deposit has been pretty completely mined out, except for ore located in the mine floor by drill holes into the Quimbys Mill member of the Platteville formation. The quantity and grade of this ore are not known.

Meloy (Fields-Meloy) and Robson mines (pl. 1, no. 38).—The Meloy mine (fig. 81) is in the SE¼SE¼ sec. 14, T. 1 N., R. 1 E. The Robson mine is just west of the Meloy mine, in the SW¼SE¼ sec. 14, T. 1 N., R. 1 E. (pl. 5). Both of these mines underlie the shallow workings of the McGinnis and Dowd lead ranges, which were mined before 1860. The Robson was operated in 1906 for smithsonite and the ore was milled at the nearby Sally Waters mill. The shaft is 95 feet deep. The Meloy or Fields-Meloy zinc deposit was discovered in the drilling of the Vinegar Hill Mining Co. about 1916, and mining was commenced in 1917 with the sinking of the shaft 130 feet to the Spechts Ferry member of the Decorah formation. The mine was operated until the end of 1920 by that company. In addition the jig tailing pile was reworked in a small flotation mill by the Chestnut Hill Mining Co. in 1944–50, and additional zinc recovered from it.

From March 4, 1917, to the end of that year, the ore averaged 10.8 percent zinc. In 1920, 3,525 tons of zinc concentrate were shipped from the mine. Ore mined from the Meloy mine totaled 160,000 tons.[42]

The Robson mine partly underlies the McGinnis lead range. Mining was carried out along a south-dipping east-striking pitch for several hundred feet to the west of the Robson shaft where the pitch turns north and then around east under the old Dowd lead range, 400 feet north of the McGinnis lead range. Smithsonite and galena were mined from beds as low as the blue beds of the Decorah formation.

The Fields-Meloy mine ore body has a general N. 80° W. trend. At the west end the oxidation extends very deep and most of the ore has been altered to smithsonite. The ore body lies along the south flank of the east-trending syncline that contains the Hoskins-Fields mine to the east (p. 119–120). The ore for the most part is veins in the lower Prosser cherty member of the Galena dolomite and in other strata downward to the base of the Guttenberg member. Some of the ore in the Prosser member is in solution breccia.

Jug Handle mine (pl. 1, no. 39).—The Jug Handle zinc mine, in the NW¼NW¼NE¼ sec. 14, T. 1 N., R. 1 E., was started about 1901 and was operated at inter-

[41] Compiled from production data furnished by the Vinegar Hill Zinc Co. and New Jersey Zinc Co.

[42] Data furnished by the Vinegar Hill Zinc Co.

The linear ore body is large and lies within a N. 25° W. trending syncline at its intersection with a northeast-trending syncline. The ore body is controlled by northwest-trending reverse fault zones. The southwest fault zone dips toward the southwest and the northeast one dips toward the east. The pitches tend to converge toward the south.

The ore, sphalerite and galena fairly rich in iron, occurs in thick sheets along the well-developed pitches and flats. It is found in all the beds from the Prosser member downward to the Spechts Ferry member, and the stops are 50 feet high in places. Mineable ore remains in the northwest mine face.

New Birkett mine (pl. 1, no. 54).—The New Birkett mine (pl. 19) is in the SE¼SW¼ sec. 18, T. 1 N., R. 1 E. The zinc ore body was discovered about 1920 by Vinegar Hill Mining Co.'s drilling. The mine was opened in the latter part of 1942 by the New Birkett Mining Co. and was closed in September 1944. The shaft is 246 feet deep, and penetrates into the Quimbys Mill member. The linear ore body has a N. 10° W. trend, a length of 1,150 feet, and a width of 10 to 100 feet; the stopes are from 10 to 20 feet high. This mine and the nearby Jefferson, Birkett, and Byrnes mines have been reopened and operated intermittently by the Eagle Picher Co. 1953–1957 as their Birkett mine.

The mine produced 20,000 tons of ore that averaged about 5 percent zinc during the period of operation by the New Birkett Mining Co.[45] In September 1943 a small jig mill was installed and the ore concentrated to an average of about 20 percent zinc before shipment to the Vinegar Hill custom flotation mill at Cuba City, Wis. The ore body did not contain the expected tonnage of ore, apparently owing to selfsalting of the drill holes by the disseminated ore in the altered rock. The mine was closed before a large financial loss was incurred. Pumping costs were high; the amount of water pumped was initially 3,500 gallons per minute but later diminished to about 1,800 gallons per minute. Headings at the north and south ends of the mine contain narrow faces of good ore.

The geology of the ore body has been described (p. 125.) The ore occurs as disseminated crystals, as small veins, and as irregular breccia fillings in the Guttenberg, Spechts Ferry, and Quimbys Mill members. Like most disseminated deposits, the ore is very lean in iron sulfide, and galena is not abundant.

Birkett mine (pl. 1 no. 55).—The Birkett mine (fig. 82) is in the northwest corner of sec. 19 and in the southwest corner of sec. 18, T. 1 N., R. 1 E. The zinc-lead ore body was found in 1925 by drilling of the Vinegar Hill Zinc Co. Operations commenced in early 1926 with the sinking of the shaft to the Spechts Ferry member at a depth of about 235 feet. The mine was operated until November 11, 1929. The mine was reopened by the Eagle Picher Co. in 1953 and has been operated by them intermittently since that time. Access is by an incline westward whose mouth lies east of the New Birkett mine.

The mine probably produced about 800,000 tons of ore before 1930.[46] The pumping problem was serious, and 1,500 gallons of water were pumped per minute, eventually leading to the closing of the mine in 1929.

The ore body is shaped like a crescent wrench. The southern end of the mine is nearly connected by ore to the Byrnes mine to the southeast. The west end of the mine is a continuation of the Jefferson ore body, to the northwest (pl. 5).

The ore body lies within, and is controlled by, the northwest-trending Kennedy syncline (pl. 5). At the north end of the Birkett mine a northeastward-trending syncline crossed the Kennedy syncline. The ore in the mine is in veins along pitches and flats in all the beds from the lower Prosser cherty member downward to the base of the Guttenberg member. In places, the ore body is exceptionally high grade, and all the headings in the mine contained some ore when closed.

Byrnes mine (pl. 1, no. 56).—The Byrnes zinc-lead deposit (fig. 82), in the NW¼ sec. 19, T. 1 N., R. 1 E., was drilled in 1927 by the Vinegar Hill Zinc Co. Mining commenced in 1928, the mine being operated in conjunction with the Birkett mine to the north until November 1929. A 1,300-foot haulage drift connects the two mines. The ore was milled by gravity methods at the Birkett mine. The shaft, at the northwest end of the mine on the east side, is about 240 feet deep. The mine was reopened in 1953 by the Eagle Picher Co. and operated by them as part of their Birkett mine.

The mine probably produced about 700,000 tons of ore in 1928–29. Pumping costs were high, as it was necessary to pump 1,500 gallons of water per minute to drain the mine, but it is reported to have been a profitable operation for the most of the 2 years.

The ore body is of the linear northwestward-trending type and is controlled by the Kennedy syncline in which it lies. It is governed by a well-developed pitch that dips to the northeast. The ore occurs in the lower Prosser, the Ion, and the Guttenberg members as thick veins in well-developed pitches and flats. The flats extend a considerable distance into the core area southwest of the main pitch.

Possible ore body extensions are (1) southeast toward the Monmouth mine, (2) northward toward the Birkett

[45] Data furnished by the Vinegar Hill Zinc Co.

[46] Data furnished by the Vinegar Hill Zinc Co.

mine, (3) westward toward the Hazel Green mine (pl. 5), (4) in Quimbys Mill beds in the floor.

Mermaid mine (*pl. 1, no. 57*).—This old lead mine, in the NW¼SW¼ sec. 19, T. 1 N., R. 1 E., was developed by the Crawford Mining Co. and produced large quantities of galena during the nineteenth century until about 1900. Zinc ore was found in the mine about that year below the water table near the top of the Prosser cherty member. The mine was operated in 1901–1902 and 1904. A small jig mill was operated at that time. The mine is said to have been unsuccessful as a zinc mine. About 250 to 300 gallons of water per minute was pumped to keep the mine drained, and this quantity of water, excessive for that time, led to the mine name (Bain, 1906, p. 88).

The ore body is a gash-vein deposit along vertical joints and in solution breccias within openings.

Murphy mine (*also Last Chance or Bininger*) (*pl. 1, no. 58*).—The location of this zinc-lead mine is the northeast corner of the SE¼SW¼ sec. 19, T. 1 N., R. 1 E. The mine was in operation in 1903 but was shut down in 1904, and some attempts to reopen it were made from then until 1909. It had a well-equipped jig-mill that was used only briefly. Very little stoping was done, and the mine was a financial loss to the operators. Drilling by the company and also later by other prospectors found little ore at depth.

The mine has three shafts in an east-trending line, all between 135 and 140 feet deep, within an area of shallow, old lead workings.

The ore is in gash-veins along a vertical, east-trending mineralized joint and in the adjacent rock. Vein sphalerite and galena ore occurs along fractures, and also replaces solution breccias. The ore is deposited along the joints at depths of 76 to 105 feet in the Stewartville member, from just below the upper *Receptaculites* zone to a short distance above the Prosser.

Monmouth and North Monmouth mines (*pl. 1, no. 59*).—The Monmouth mine (fig. 82) is in the center of the SE¼ sec. 19, T. 1 N., R. 1 E. The North Monmouth ore body, northwest of the Monmouth mine, is connected with it by a drift about 1,100 feet long. The Monmouth zinc-lead ore bodies were discovered and profitably mined by the Vinegar Hill Mining Co. (renamed the Vinegar Hill Zinc Co. after 1925) from 1924 to January 1928. The shaft is 215 feet deep. In 1944–47 a small mining company mined the remaining ore in the top part of the North Monmouth ore body. Water presented a serious problem, and about 1,200 gpm of water was pumped. The Monmouth mines produced several hundred thousand tons of about 4 percent zinc and 8 percent lead ore.

In general the two ore bodies trend parallel to, and lie within the northwestward-trending Kennedy syncline. Both ore bodies have unusual patterns in plan, apparently owing to control by a combination of the northwest-trending fold and transverse eastward-trending folds. The shape of the main Monmouth ore body is similar to a question mark. It is controlled by a well-defined northeastward and eastward-dipping pitch that at the north loops around to the west and then to the south, forming a nearly complete ellipse. The central core area was too lean to mine except locally.

The drift to the ore bodies was cut through the Quimbys Mill, Spechts Ferry, and Guttenberg members; these rocks are cut by small thrust and normal faults and folded into small overturned, recumbent and fan folds that have N. 80° E. axial trends. The small complex structures are absent where a gentle northeastward-trending anticline is crossed in the central area of the drift, but they increase in number toward the ore bodies at the ends of the drift (Leith and Lund, 1926).

The North Monmouth ore body is in the form of an *S*, with prongs that extend a few hundred feet to the northwest and southeast along the trend of the Kennedy syncline. The ore bodies of both mines are in rocks from the Prosser cherty member down to the base of the Guttenberg member. The ore in a "top-run" above the North Monmouth mine is in the top of the main pitch zone in the Stewartville member, about 200 feet above the Guttenberg.

Trewartha mine (*pl. 1, no. 60*).—The Trewartha mine (fig. 82) is in the center of the S½ sec. 20, T. 1 N., R. 1 E. The zinc-lead ore body was found in 1931 by the drilling of the Vinegar Hill Zinc Co. Mining began in February 1932 with the sinking of the shaft to the top of the Spechts Ferry member at a depth of 153 feet and continued until the autumn of 1934. About 600 gallons of water were pumped.

The ore body, which is in two parts separated by an unmineralized area, has a northeast trend. The southwest part of the ore body is controlled by a well-developed southeast-dipping pitch of northeast strike, the base of which follows the southeast mine wall. Locally, northwest of the shaft, a north-dipping pitch was found along the northwest wall of this part of the ore body. The northeast part of the ore body is controlled by an extension of the main pitch of the southwest part of the ore body. The ore body is on the south flank of the northeast-trending Crawford-Martin syncline (pl. 5). Veins of ore in the well-developed pitches and flats are accompanied by some breccia ore, and ore-lined solution cavities in the rock. The ore is deposited in the Decorah formation. Considerable galena was mined from the Guttenberg member.

Strawberry Blonde mines (pl. 1, no. 61).—The old and new Strawberry Blonde zinc mines (pl. 5) are in the SW¼SE¼ sec. 21, T. 1 N., R. 1 E. The old Strawberry Blonde operated from 1900 to 1903; brief descriptions are given by Grant (1903, p. 73) and Bain (1906, p. 88). The shafts and adits of the old mine indicate that the small zinc ore body had a southward trend, in addition to the east trend described by Grant.

The New Strawberry Blonde mine is about 600 feet south of the old Strawberry Blonde mine, on both sides of the old Strawbridge railroad tunnel. It was opened in the spring of 1941 and operated until November 1942. The zinc ore body trends N. 10° W. and has been mined for a length of 400 feet, to a width of 30 to 70 feet, and to a height of 6 to 10 feet. The ore was hoisted up a shaft about 80 feet deep, approximately 150 feet south of the tunnel, even though it could have been removed easily through the tunnel.

The new mine produced an estimated 2,000 tons of ore averaging 10 percent zinc. A little lean ore is exposed in the north and south headings. No attempt was made to discover ore at deeper horizons.

The ore body is a breccia deposit of light yellow brown sphalerite in the lower Receptaculites beds of the Prosser member. It is controlled by a reverse fault adjacent to the west of the breccia zone that strikes N. 10° W. and dips 45° to the east. Other parallel unmineralized reverse faults are exposed in the tunnel for a distance of 200 feet west of the ore body. Both ore bodies lie on the east flank of the northwest-trending Frontier-Strawbridge syncline.

Consolidated mine.—This deposit, in the center of the N½NW¼ sec. 21, T. 1 N., R. 1 E. (pl. 5), was drilled in 1907 by Edward Longhenry and subsequently by the Wisconsin Zinc Co. and the Vinegar Hill Mining Co. It was mined briefly in 1946 and 1947 by the Consolidated Mining Co., but the ore was too lean to be mined at a profit.

The shaft is between 120 and 150 feet to the top of the Guttenberg member. A stope extends northeast from the shaft for 200 feet, which is 15 feet high at the north end and 20 feet wide. Another stope extends southwest from the shaft for 50 feet, which is 15 feet wide, but only 5 feet high. The ore is in thin veins of sphalerite and marcasite in the Ion member of the Decorah formation as a breccia and in flats, rich in iron but lean in zinc.

The mine is at the northwest corner of the junction area of second-order synclines that trend northeast and northwest. This area is unusually favorable structurally for zinc deposits because of the intersection of these synclines. In the valley to the south outcrops show marcasite-filled fractures and bedding planes filled with sphalerite crystals, and old drill holes to the south and east of the mine in sec. 21 are reported to have found zinc ore.

Jack of Diamonds mine (pl. 1, no. 62).—The Jack of Diamonds mine, in the NW¼SE¼ sec. 22, T. 1 N., R. 1 E., was opened in 1902 and operated by the Jack of Diamonds Mining Co. until about 1906. The workings are 700 feet long and 30 to 70 feet wide. The stopes are 6 to 12 feet high; and the roof, which was shored up by wooden posts, is dangerous. Nothing is known as to the water problems or production of the mine, but the latter was certainly not large. The mine was equipped with a 100-ton jig mill, which was operated for only short intervals.

The ore body trends N. 40° W. and is controlled by a pitch parallel to it that dips to the southwest. The sphalerite and galena ore is very rich in iron sulfide and was mostly mined from the Quimbys Mill member. Lean zinc sulfide and abundant marcasite ore is in the overlying beds, and galena and smithsonite were mined from both northwestward- and eastward-trending joints in a small open cut above the northwest end of the stopes; similar ore in the beds overlying the rest of the mine has not been taken out.

Drill holes showed sphalerite and abundant pyrite and marcasite all through the Platteville formation, but most of this mineralized rock is too lean to mine for zinc, and in part may be due to self-salting of the drill holes.

Ollie Bell mine (Kerwin mine, Curwin and Miller mine, or Leekley mine) (pl. 1, no. 63).—This mine (fig. 82), in the NE¼NW¼ sec. 22, T. 1 N., R. 1 E., was in operation for a number of years prior to 1900 under the name of Curwin and Miller. A level was driven south into the bank of the Fever (now called the Galena) River for several hundred feet, and a shaft 186 feet deep was sunk from the top of the hill into the ore body. The mine was operated for smithsonite until 1900.

Thick veins of sphalerite were cut by the shaft in the Quimbys Mill member, and this ore was being mined about 1900 (Dugdale, 1900, p. 32). Mining continued at intervals until 1906 when the mine was closed. The New Jersey Zinc Co. reopened the mine in 1909, and a large mill and underground incline to the one in the Quimbys Mill were constructed. It was operated until February 11, 1911.

The production from this mine is not known, but it was fairly large for the short period of operation. Probably a small amount of water was pumped from the lowest workings.

At the southwest corner of the mine is a drift 500 feet long and 10 feet wide along an ore-bearing vertical fracture striking S. 10° W. The main ore body trends east-west, and the ore is reported to be in well-developed pitches and flats, and in a large flat in the Quimbys Mill member.

Some replacement sphalerite occurs in the blue and gray beds of the Decorah formation, and smithsonite was mined in the Prosser cherty member of the Galena dolomite. At the mouth of the adit the beds strike S. 72° E. and dip southerly; this strike and dip tends to corroborate reported east-west structures of the main ore run. Also, at the adit mouth a set of vertical joints was found striking about S. 12° W.

Curwen mine (pl. 1, no. 64).—The Curwen mine (pl. 22) is in the NE¼NE¼ sec. 22, T. 1 N., R. 1 E. The zinc ore body was discovered by John S. Curwen about 1924 by shaft-sinking. A small amount of mining was done by him at intervals from 1924 to 1942. The mine produced ore fairly continuously from January 1942 until April 1945, when it was closed. It was first operated as "Longhenry and Curwen" and later by the Curwen Mining Co.

The mine produced an estimated 4,000 tons of zinc ore that averaged 14 percent zinc between January 1942 and April 1945. About 50 gallons of water per minute was pumped. The mine is worked out except for the possibility of some deeper ore in the McGregor member beneath the Quimbys Mill. However, this type of ore seen in the mine appeared to be too local to be profitable.

The ore body trends N. 30° W. and is reached by several shafts. The main shaft is 36 feet deep and extends 3 feet into the McGregor member of the Platteville formation.

The ore body lies within a local northwest-trending syncline. Within this syncline are intersecting northwest-trending crenulations that trend N. 30° W. and N. 70° E. The ore body is controlled by a bedding-plane fault extending through the entire area opened by mining. This fault, which is just above the base of the Quimbys Mill member, contains the main ore veins. Incipient pitches are in the northeast and east parts of the mine. A fairly well-developed fracture, which contains some ore at the north end, strikes N. 30° W., and dips 45° NE., and bounds the ore body on the northeast side. A network of small vertical fractures that strike mostly northwest and northeast are present in various parts of the mine. In one place in the east-central part of the mine a N. 30° W. pitch extends down into the McGregor member.

Most of the ore occurs as a flat, 6 inches to 1 foot thick, in the main bedding-plane fault and extends over nearly the entire area mined. The ore is high grade in most of the mine, but the marcasite and pyrite content increases near the borders of the ore body so that there the vein is composed almost entirely of these iron sulfides. Calcite is very uncommon and galena not abundant. The ore flat is thickest beneath the pitches, in areas of crossing vertical fractures, and in small synclines; it is thinnest over the small anticlines. The main local syncline rises to the north, and the ore becomes more oxidized in this direction.

Sally Waters or Monarch mine (pl. 1, no. 65).—This mine (fig. 83), in the NE¼NE¼ sec. 23, T. 1 N., R. 1 E., was first opened in 1902 on an old "drybone range" by the Consolidated Lead and Zinc Co. A shaft 75 feet deep was sunk into the blue beds of the Decorah formation. The mine was later taken over by the Monarch Zinc Co., and a considerable quantity of zinc ore was mined until about 1910 when the company went into receivership. The Sally Waters was reopened in January 1917 by the Vinegar Hill Mining Co. through a haulage drift driven southward from the Meloy mine. Very little ore had been left from the previous operations, and the mine was soon abandoned. A little work was done in the north part of the mine about 1941, probably robbing. In October 1944 some prospecting was started near the south end of the mine, at the surface; in March 1945, a small open cut was made to recover some zinc ore left near the surface. A small quantity was mined, but the operation was soon abandoned.

This mine undoubtedly produced a considerable tonnage of ore, but the only recorded amount is 4,088 tons of 7.2 percent zinc ore mined by the Vinegar Hill Mining Co. in 1917.[47] The roof in the south part is in very bad condition and has caved locally to the surface.

The Sallie Waters mine is a typical eastward-trending arcuate ore body controlled by pitches and flats. Three flats along probable solution-sag beneath vertical fractures radiate outward for a short distance from the pitch.

The main ore body consists of veins in well-developed pitches and flats in all the beds from the Prosser cherty member down to the Guttenberg member. Considerable quantities of smithsonite were mined above the water level. A little ore was mined from the Quimbys Mill member in the south part of the mine, in a breccia with much calcite. Very little ore was found in the footwall area away from the pitches.

Penna-Benton mine and Expansion mine (pl. 1, no. 66).—The Penna-Benton mine (fig. 83), in the SW¼SW¼ sec. 24, T. 1 N., R. 1 E., consists of two separate arcuate zinc-lead ore bodies, and the west part of a third, all connected by drifts. The mine is opened by two shafts; the northeast one is 170 feet deep, and

[47] Data furnished by the Vinegar Hill Zinc Co.

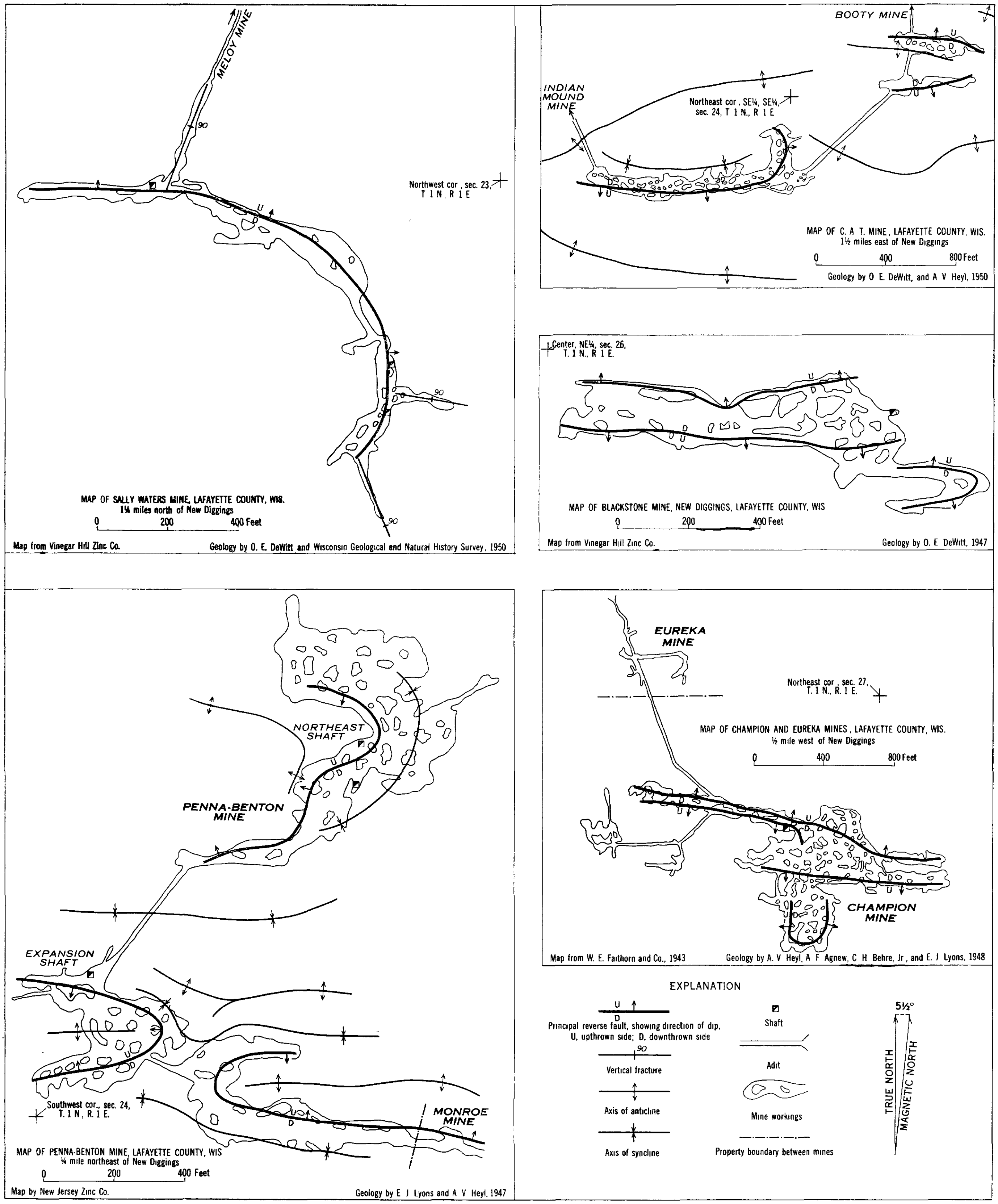


FIGURE 83.—Maps of Sally Waters, Penna-Benton, C. A. T., Blackstone, Champion, and Eureka mines.

the southwest one or Expansion shaft is 115 feet deep. The Expansion mine, of the 1899–1900 period, reopened the Crossmans diggings first operated in 1836. The northeast shaft of the Penna-Benton mine was sunk about 1914 by the New Jersey Zinc Co., and the mine was opened on that ore body in 1915, and operated successfully until September 22, 1921. Between December 1946 and June 1947, the Little Benny Mining Co. was engaged in robbing the mine.

The mine produced 850,000 tons of ore from 1915 to 1921.[48] Although the mine was partly robbed, some ore remains in places and probably some ore in the Quimbys Mill remains locally in the floor. A lean ore body lies between the north ore body and the Lucky Twelve mine, to the east.

The sphalerite and galena ore is in veins that fill well-developed reverse and bedding-plane faults in all the beds from the Prosser cherty member down to the Guttenberg member. In the upper levels some solution breccia ore is present.

Structurally the three ore bodies of this mine are unusual; for in each one the arcuate fault zones surround and flank an anticlinal nose, instead of the more common relationship of surrounding a synclinal nose.

Lafayette (Lake Superior) mine (pl. 1, no. 67).—The Lafayette mine is just west of the center of sec. 24, T. 1 N., R. 1 E. The original discovery was made about 1906 by the Lafayette Land and Mining Co. on the south part of the property, where a near-surface gash-vein zinc deposit was mined for 250 feet in an east direction between two shafts. The property was later taken over and was drilled by the Lake Superior Mining Co. On the basis of one drill hole reported to contain ore a shaft was sunk in the north part of the SE¼NW¼ sec. 24, T. 1 N., R. 1 E. to the depth of 120 feet through the Quimbys Mill member. A mill was built; and a tramway southward to the older Lafayette mine was erected. The north shaft, called the Lake Superior, contained no ore, no stoping was done. A little more mining was done in the Lafayette mine, but the operation was soon abandoned at considerable loss.

Lucky Twelve mine (pl. 1, no. 68).—The Lucky Twelve mine (fig. 84) is in the center of the S½S½ sec. 24, T. 1 N., R. 1 E. The zinc ore body was discovered by drilling about 1910 by the Lucky Twelve Mining Co. Operation of the mine commenced in about 1911 and continued apparently successfully until about 1915. The Cleveland Mining Co. later operated the mine. The shaft is about 165 feet deep.

The production from this mine is not known but probably ranged between 100,000 and 250,000 tons. The jig concentrate ran as high as 56 percent zinc in grade.

[48] Data furnished by the New Jersey Zinc Co.

The ore body is a typical eastward-trending arc in pattern, open to the west, and it is controlled by an outward-dipping reverse fault system that flanks an eastward-trending syncline. The ore occurs only locally along the fault system and the mine consists of four areas of stopes, connected by drifting along the barren parts of the fractures. The ore is mostly veins of sphalerite of a high grade, that are in the pitches and flats.

Indian Mound or Murphy mine (pl. 1, no. 69).—This zinc-lead deposit, in the NW¼SE¼ sec. 24, T. 1 N., R. 1 E., was discovered by drilling, probably about 1917–1918. The mine (fig. 28) was in operation by the Cleveland Mining Co. about 1919 and 1920. Later the Wisconsin Zinc Co. drove a drift northwest from the C. A. T. mine to this mine, and additional mining was done at the east end by that company, probably about 1922–1923.

The mine profitably produced a fairly large tonnage of ore, estimated to be between 200,000 and 500,000 tons, but the actual production is not available.

The ore body is a typical eastward-trending arc that lies on the flanks of a clearly-defined eastward-trending syncline, and the ore body is controlled by an outward-dipping pitch zone. The veins of sphalerite, marcasite, pyrite, and galena are of a good grade, and are deposited in the well-developed pitches and flats.

C. A. T. mine (pl. 1, no. 70).—This deposit (fig. 83), in the SE¼SE¼ sec. 24, T. 1 N., R. 1 E., and the NW¼SW¼ sec. 19, T. 1 N., R. 2 E., was discovered by the Wisconsin Zinc Co. in February 1914. In about 1916 mining was commenced by that company with the sinking of a shaft to a depth of approximately 120 feet. The mine was operated successfully until early in the 1920's, and produced a large tonnage of ore.

The mine is in two ore bodies, both of which are eastward-trending arcs in plan. The smaller arcuate ore body lies to the northeast and was mined from the main C. A. T. mine by a 700-foot connecting drift. The smaller ore body consists of two east-trending limbs, which drilling showed to converge and form an arcuate nose at the east end. However, the ore becomes so lean at the arcuate nose that it was not mined.

In both ore bodies the zinc and lead ore is deposited in well-developed pitches and flats as veins. In the main C. A. T. ore body the stopes are about 60 feet high and all the beds from the lower Prosser member downward to the Guttenberg member were mined. The smaller ore body is in a much smaller thickness of mineralized rock.

Fields "Upper Run" mine (pl. 1, no. 71).—The zinc ore body was discovered in drill holes in the S½NE¼ sec. 25, T. 1 N., R. 1 E., the mine opened and operated

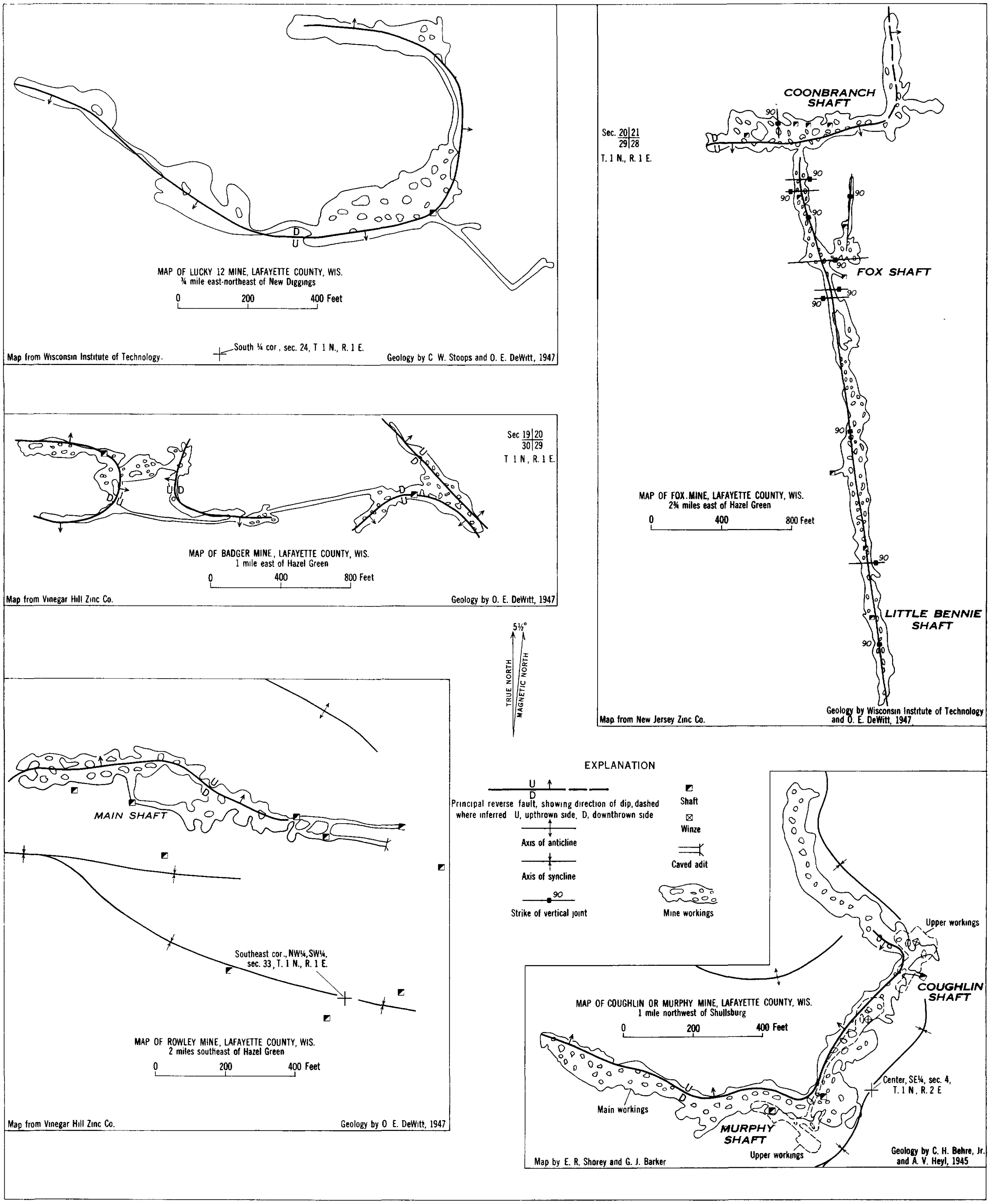


FIGURE 84.—Maps of the Lucky Twelve, Fox, Badger, Rowley, and Coughlin (or Murphy) mines.

for one year sometime between 1910 and 1920. The Wisconsin Zinc Co. drilled the property in 1920 without great success.

The shaft is 208 feet deep to the Guttenberg member. Drifts were driven 350 feet west of the shaft, and 250 feet east of the shaft. The maximum width of the stopes is 50 feet but this width narrows to 6 feet at the headings. The stopes are 25 feet high at the shaft. The mine was shut down when the grade of unsorted ore decreased to 6 percent zinc. Only a small amount of water had to be pumped.

The ore body is controlled by a south-dipping, eastward-striking pitch, probably the same as seen in the Thompson mine to the east and the Blackstone mine to the west (pl. 5). The ore body lies within an east-trending linear syncline that includes all these mines, but the syncline is less developed here than at the other mines. The ore is vein sphalerite in the blue and gray beds of the Decorah formation.

The name "Upper Run" was applied to this mine in 1940 when the Moore Brothers mined lead and zinc sulfide ore from the same shaft, at a depth of only 83 feet. The upper lead-rich workings, probably at the top of the Prosser cherty member, extend about 500 feet east and a similar distance west from the shaft. The stopes are about 30 feet wide and 20 feet high and are in the upper part of the south-dipping pitch zone above the older, deeper workings.

Monroe, Longhorn, and Little Joe mines (pl. 1, no. 72).—These mines (pl. 16) were developed in a large arcuate zinc-lead ore body in the N½NW¼ sec. 25, and a small elliptical ore body in the SE¼SE¼SW¼ sec. 24, T. 1 N., R. 1 E. The mine was worked as the Longhorn mine by the Wisconsin Zinc Co. from about 1917 to about 1920. The three main shafts of the mine are: (1) the Little Joe at the southwest end of the ore body, 127 feet deep to the Spechts Ferry member; (2) the Longhorn at the southeast corner, 128 feet deep to the base of the Quimbys Mill member; and (3) the Monroe on the north limb, 102 feet deep to the base of the Quimbys Mill member.

The Monroe part of the mine was reopened by the Little Benny Mining Co. in August 1941 as the "Monroe" mine, and robbing of that part was completed; the underlying Quimbys Mill run in the Monroe mine was mined; and the company also mined the North Monroe ore body. The mine was closed in January 1945.

In October 1945 they reopened and deepened the Longhorn shaft and until August 1947 mined a good grade of ore from the Quimbys Mill member beneath the old stopes.

The Little Joe shaft was reopened October 1942 by the Van Gordin Mining Co., and the part of the mine on the Thompson property was robbed, and new stoping was done in the mine floor and roof. This company operated until January 1945 when the closing of the Monroe mine to the north flooded their stopes. The Van Gordin Mining Co. reopened the Little Joe mine in October 1945, when the mine was drained by the reopening of the Longhorn mine, and it operated intermittently on a small scale until March 1946.

The Wisconsin Zinc Co. may have produced as much as 600,000 tons of ore from the main ore body, as indicated from the size of the stopes, in the first period of production from 1917 to 1920. The Little Benny Mining Co. in 1941–1945 produced 6,000 tons of 30 precent zinc concentrate from both ore bodies,[49] and the Van Gordin Mining Co. produced an estimated 11,000 tons of hand-sorted 7 percent zinc ore. All of the operations apparently were profitable ventures.

The Monroe-Longhorn-Little Joe deposit is a large, east-trending arcuate ore body open to the west, and the North Monroe ore body is a complete ellipse. The geology of these deposits has been previously described (p. 122).

Blackstone mine (pl. 1, no. 73).—The Blackstone mine (fig. 83) is in the SE¼NE¼ sec. 26, T. 1 N., R. 1 E. The zinc ore body was discovered by drilling in 1915, by the Vinegar Hill Mining Co., and was opened by this company on April 6, 1916, through a shaft 166 feet deep to the Spechts Ferry member. The mine was operated by the Wisconsin Zinc Co. in 1919 and 1920, and by the New Jersey Zinc Co. in 1925–1926.

While operated by the Vinegar Hill Mining Co. in 1916–1917, the mine produced 150,000 tons of ore averaging 8 percent zinc.[50] In 1925–1926 the New Jersey Zinc Co. produced zinc ore from the mine yielding 32 percent zinc concentrate.[51] The total production of the mine is probably between 300,000 and 500,000 tons of ore. A large body of ore remains west of the mine toward the Champion mine, which is known as the Champion Church ore body.

The ore body is of the eastward-trending, linear, double-pitch type, and has a smaller eastward-trending arcuate ore body attached at the southeast end. They lie within the eastward-trending Champion syncline (pl. 5) that also contains the Field's "Upper Run" mine. The pitches are probably a continuation of the fractures that control the Champion ore body to the west. The sphalerite ore in many places is rich and occurs in the blue and gray beds of the Decorah formation, and the lower Prosser member of the Galena

[49] Data furnished by the Little Benny Mining Co.
[50] Data furnished by the Vinegar Hill Zinc Co.
[51] Data furnished by the New Jersey Zinc Co.

dolomite. In the lower beds the ore is vein sphalerite and marcasite and in the upper strata the ore is in solution breccia.

Champion and Eureka mines (pl. 1, no. 74).—The Champion mine (fig. 83) and the smaller Eureka mine to the north are in the NE¼ sec. 27, NW¼ sec. 26, and SW¼SE¼ sec. 22, T. 1 N., R. 1 E. The Eureka mine was operated from about 1895 to 1903 through the adit, driven S. 25° E. into the hill (Dugdale, 1900, p. 23). Some galena was mined along this adit; and about 300 feet from its mouth a small arcuate zinc ore body was mined in the blue and gray beds and the Guttenberg member of the Decorah formation.

The Champion mine is at the west end of the old, important Champion lead ranges. The Champion zinc-lead ore body was found about 1913 in drilling by the Wisconsin Zinc Co. It has been developed during several periods of operation into one of the large, reportedly profitable mines of the district. The Wisconsin Zinc Co. commenced operations in 1914 with a 160-foot main shaft, and operated continuously until 1921. The mine was reopened in 1925 by the New Jersey Zinc Co. and closed again in 1927 when that company left the district. In late 1944 the W. E. Faithorn Co. deepened the main shaft 10 feet and mined some of the ore remaining in the Quimbys Mill member. This company mined ore and reworked old tailings until 1946 using their own gravity and flotation mill. The mine is owned by the American Zinc, Lead and Smelting Co.

The mine has produced more than 1,000,000 tons of ore. From 1944 to 1946 the mine is estimated to have produced 75,000 tons of zinc ore. Pumping costs were low, as the mine drains through the Eureka adit to the north, and the remainder of the water can be used in the milling of the ore.

The ore body is controlled by a complex fracture system. It is an eastward-trending, linear, double-pitch ore body having north and south-dipping pitches; it lies near the west end of an eastward-trending basin. Southeast of the main shaft and of the main south pitch is an arcuate, outward-dipping pitch, controlling a large body of ore. At the west end of the mine the main pitches may curve together and join to form an arcuate nose.

The ore body contains good vein ore in well-developed pitches and flats in all the beds from the top of the Prosser cherty member to the base of the Quimbys Mill member, a total ore-bearing thickness of more than 150 feet. Much of the ore in the Prosser cherty member is sphalerite and galena rich in iron sulfides that cement solution breccias.

American Zinc Thompson mine.—A mine was opened in two zinc ore bodies about 1956 on the Thompson property about one half mile south of the Champion mine in the SE¼ sec. 27, T. 1 N., R. 1 E. by the American Zinc, Lead, and Smelting Co. The main access is by a truck incline extending northward from the Temperly property to the south. The larger ore body, the Thompson, was found in 1953 by C. W. Tandy. Geologist for the Vinegar Hill Zinc Co. by drilling. It is elliptical in outline. The mine was still in operation in June 1957. Ore is milled at Shullsburg at the American Zinc Co.'s mill.

Old Occidental mine (pl. 1, no. 75).—This very old zinc-lead mine is in the SW¼SE¼ sec. 27, T. 1 N., R. 1 E. This mine was opened by Harper, Hird and Co. in 1873. Moses Strong (1877, p. 711) gave the following brief description of it:

> The existence of lead and zinc ore in the upper pipe-clay opening (upper surface of the Blue limestone) [Guttenberg and Spechts Ferry members of Decorah formation] is also known at New Diggings. A mining company, known as the Occidental, was in operation in 1873, by whom a level had been run on this opening, which resulted in the discovery of a flat sheet of blende on lead ore. No work has been done here recently, but the prospect is considered good.

Apparently some work was done at a later date as, in addition to the old small dumps, some larger and newer dumps are on the property.

Near the south section line of section 27 and adit was driven S. 80° E. into the hill from the east bank of the Galena (Fever) River. About 650 feet to the north are two old, caved adits, 30 feet apart, which trend easterly. All three adits have fairly large dumps, rich in lead and zinc ore. Galena is disseminated as crystals in Guttenberg strata that are altered to shaly residues by solution. Sphalerite occurs in veins and replacements in the Ion and Guttenberg members of the Decorah formation; the ore is low in iron sulfide.

A northward-trending drift about 800 feet long is supposed to connect the three adits some distance to the east of their portals. A shaft has been sunk from the top of the hill about 300 feet east of the northernmost of these adits, the dump of which has some good zinc ore very rich in iron. The extent and trend of the ore body or ore bodies mined by these workings is not known. In 1915 the Frontier Mining Co. did some drilling to the east, but the holes are widely scattered and the results are not known. Nothing is known of the production from this mine.

Longhenry or Spensley mine (pl. 1, no. 76).—The Longhenry mine is in the NW¼NE¼ sec. 28, T. 1 N., R. 1 E. Prior to 1913 E. G. Longhenry sank several shafts and drilled 50 prospect holes on the Spensley property (pl. 5). This drilling showed zinc ore in the

Guttenberg that has a north trend. At the north end of this drilling a 140-foot shaft was sunk reportedly into the blue beds of the Decorah formation. The dump of the north shaft contains considerable zinc ore. At the south end a second shaft probably was sunk to the top gray beds of the Decorah formation at a depth of 90 feet. An unmineralized east-trending inclined fracture that dips to the south was found at the base of the south shaft. Drifts were driven 30 feet east and 30 feet north from this shaft, and at the north end of the north drift, a vein of sphalerite is reported to be in the floor. It is also reported that the remaining 400 feet of this ore body between the two shafts has not been mined.

The Longhenry mine shaft is a few hundred feet west of the south shaft mentioned above. This mine is 300 feet long, 50 to 100 feet wide, and "post high" (about 6 feet). As in the other ore body it was developed in a north-trending ore run. The Longhenry shaft, about 116 feet deep, appears to have penetrated the Guttenberg member and cut a good zinc ore flat at the top of these beds. But apparently most of the ore was obtained from the Ion member, and some ore is said to remain north of the workings. The Longhenry mine was operated sometime between 1915 and 1925, but little is known of its production except that it was small. The mine had a small jig mill.

A shallow shaft a few hundred feet northwest of the Longhenry shaft, near the base of the bluff, cut vein and breccia zinc ore in the Quimbys Mill member, and some disseminated sphalerite in the Guttenberg and Spechts Ferry member. Also similar ores were found in a now-concealed shaft located in the valley floor a short distance to the northwest. The shaft in the valley was 25 feet deep into the Quimbys Mill member.

Fox mine (pl. 1, no. 77).—The Fox mine (fig. 84) is in the SW¼SW¼ sec. 21, and the NW¼ sec. 28, T. 1 N., R. 1 E. Drilling by the Fox Lead and Zinc Co. at old lead diggings in 1906 discovered the zinc-lead ore body. This company sank a 140-foot shaft that same year and began mining. Also in 1906, the Little Bennie Mining Co. was formed and later started mining on the south part of the same ore body by sinking a shaft to a depth of 120 feet. These companies continued in operation, and in 1909 the Coon Branch Mining Co. sank a 100-foot shaft into the north part of the ore body and commenced operations. These three operating properties, all in the same ore body, were bought by the New Jersey Zinc Co. about 1912 and operated successfully until about 1917 as the Fox mine.

The Fox mine is one of the larger mines of the district and, while operated by the New Jersey Zinc Co., the mine produced 750,000 tons of zinc-lead ore, which was concentrated by jigging to a 22 percent zinc concentrate.[52] Only a small volume of water per minute was pumped to drain the mine.

Structurally, the ore body is controlled by a combination of vertical joints, reverse faults, and folds. The long south prong of the ore body is controlled by vertical joints parallel to the ore body. The ore occurs in flats and areas of solution breccia relatively rich in iron. The ore was found in the Ion and Guttenberg members. This ore body became leaner in zinc and richer in iron sulfide at the south end near Little Bennie shaft; here the ore is reportedly restricted to the blue strata of the Decorah formation.

The N. 80° E.-trending ore run to the north has well-developed south-dipping pitches and associated flats, in which the zinc ore is in iron sulfide-rich veins. The dumps contain ore that was mined from the Prosser down to the Spechts Ferry member, and some ore was mined from the Quimbys Mill member.

Kennedy (Mills, Hoskins) mine (pl. 1, no. 70).—The Kennedy mine (fig. 28), in the SW¼ sec. 29, T. 1 N., R 1 E., is in one of the largest and most profitable zinc and lead ore bodies of the district. The original discovery of lead ore was made in 1851 by Gabriel and Henry Mills who opened the Mills lead mine. The Hoskins and Kennedy mines are on the site of the old Gillette Drybone diggings, which were worked for galena and smithsonite at least as early as the more spectacular Mills mine. By 1900 the ore body was being operated as three zinc-lead mines: (1) the Mills on the north by Jefferson Crawford Co.; (2) the Hoskins by the New Deal Mining Co. in the center; and (3) the Glanville by the Glanville Mining Co. The Hoskins mine was sold in 1902 to the Hoskins Mining Co. which in turn sold it to the Winnebago Mining Co. in 1906. The Mills mine was shut down by 1905 and reopened in 1906. Meanwhile, the Glanville had passed into the hands of the Kennedy Mining Co. In 1912 all the properties were bought by the New Jersey Zinc Co. and were operated by them until 1919 under the name of the Kennedy mine.

The original Mills part of the ore body was one of the richest lead deposits ever discovered in the district. The lead-zinc ore is in typical flats and northwest-trending pitches, with a central flat connecting the tops of the two opposing pitches. A northwest-trending vertical galena-bearing joint extended from the top flat to the surface. The top flat contains in places 2½ to 3½ feet of solid galena, accompanied by a little smithsonite. The Mills part of the ore body was worked continuously from 1851 until 1919. It was mined for galena until about 1885, when the sphalerite content so increased with depth that it became the principal ore

[52] Data furnished by the New Jersey Zinc Co.

recovered. Since that time most of the mining was for zinc.

Between 1851 and 1857, 600 tons of nearly pure galena was mined; and from 1857 to 1860 about 1,250 tons (Strong, 1877). Between 1858 and 1876, 2,200 tons more of galena had been mined, and by 1900 another 3,000 tons of galena had been produced, plus 1,000 tons of zinc concentrate (Dugdale, 1900). Between 1902 and 1905 the Hoskins mine part of the Kennedy shipped 6,000 tons of zinc jig concentrate and 400 tons of galena (Bain, 1906). The zinc jig concentrate shipped averaged about 30 percent. Each of the 3 mines had a large jig mill; the one at the Mills mine had a capacity of 300 tons. The Kennedy mill was used by the New Jersey Zinc Co. in their later work, and this company produced about 1,300,000 tons of zinc-lead ore.[53] In 1944–50 the large jig tailing piles were reworked by local companies and at least one unsuccessful attempt made to reopen the mine which was defeated by a large cave-in from the surface while the mine was being dewatered.

Access to the mine is by: (1) an incline driven westward from the valley of Bull Branch downward into the central part of the Kennedy mine; (2) the main Kennedy shaft, which is 160 feet deep; and (3) the main Mills shaft, which is 183 feet deep. Pumping at the New Deal mine in 1906 was about 700 to 800 gallons per minute, and this volume probably increased considerably as the mine was enlarged.

The ore body is more than half a mile long, trends N. 30° W., and is a typical linear northwestward-trending ore body. It has two zones of outward-dipping pitches that strike parallel to the ore body. The ore body ranges in width from 400 to 600 feet and has a height up to 150 feet in places. The pitches and flats and their associated veins of lead and zinc ore are especially well developed.

The ore body is in the Kennedy syncline (pl. 5) at its intersection with a smaller northeast syncline. Where the opposing pitches converge to about 400 feet apart in the central part of the ore body the entire central core area is of mineable grade. Where a small transverse syncline crosses, there is apparently an outward bowing of the pitches; and where a small transverse anticline crosses, an inward bowing of the pitches is found. In the central part of the mine an arcuate pitch crosses from the east to the west pitch zones and dips to the south. An east-trending branch of the ore body, controlled by north- and south-dipping pitches, extends east from the central part of the mine. This branch lies in the main transverse syncline. Extensions to the ore body are probable. The heading at the north end on the east pitch was reportedly still in good ore when mining ceased in 1919. The west pitch was not mined as far north as the eastern one and appears to turn westward where last seen; so far as is known, this possible extension has not been prospected. The east-trending ore body at the central part of the mine appears to have died out and does not seem to show much promise of extension. At the south end the west pitch was more strongly mineralized and was worked to the south property line; therefore a good heading is probably present, although it is not known how much work was done on the Big Dad mine property to the south. The east pitch appears to have weakened so much that the ore was below mineable grade at the south end, but there is the possibility of its being renewed farther south. The Kennedy mine has not been robbed, and considerable ore undoubtedly remains in the pillars.

The ore is sphalerite vein ore rich in galena; in the upper levels galena, accompanied by a little smithsonite, composed the main ore. In the lower levels, stalactitic sphalerite ore in open cavities of the veins was not uncommon. The ore is in all the beds from the upper part of the Prosser member downward to the Spechts Ferry member.

Descriptions of the ore body from the earliest days to about 1920 can be obtained from many reports (Whitney, 1862, p. 285–286); (Strong, 1877, p. 708); (Chamberlin, 1882, p. 475–477); (Dugdale, 1900); (Grant, 1903, p. 69–70); (Bain, 1906, p. 82–84); (Boericke and Garnett, 1919, p. 1223–1225, fig. 4).

Drilling by the U. S. Geological Survey (Heyl, Lyons, Agnew, 1951) to test the deeper Prairie du Chien group located pyrite and marcasite as well as silicified zones in this unit and in the St. Peter sandstone, but found no ore in these underlying rocks.

Badger mine (*pl. 1, no. 79*).—The Badger mine (fig. 84) is in the N½NE¼ sec. 30, T. 1 N., R. 1 E., and underlies the northeast part of the old Badger lead diggings, which were of great importance during the latter part of the nineteenth century. About 1900 the Crawford Mining Co. was mining lead and zinc ores from the upper parts of the pitches and flats of this ore body. In 1929 the mine was opened by the Vinegar Hill Zinc Co. through a shaft about 235 feet deep to the base of the Guttenberg member, and was operated by this company until April 17, 1933.

The mine probably has produced between 750,000 and 1,000,000 tons of zinc-lead ore. About 1,000 gallons of water per minute was pumped from this mine.

The mine contains an eastern and two western zinc-lead ore bodies, connected by drifts. The eastern ore body is in a general synclinal area that is at the junction of the Kennedy northwest-trending syncline and the northeast-trending Crawford-Martin syncline.

[53] Data furnished by the New Jersey Zinc Co.

The east pitch follows the Kennedy syncline whereas the west pitch swings from the Kennedy structure into the Crawford-Martin one.

The "west ore body" consists of two opposing horseshoe-shaped ore bodies that trend easterly and are about 300 feet apart at their convex noses. They are connected on the north side of the noses by an irregular east-treading body of ore 50 to 200 feet wide. The west ore bodies lie within a local, east-trending syncline at its intersection with the larger Crawford-Martin northeastward-trending syncline.

The ore is in the Prosser, Ion, and Guttenberg members. The Guttenberg member is altered by solution to brown carbonaceous shale, and much of it is replaced by silica in the form of chert and jasperoid. The ore in the Guttenberg member is relatively rich in iron sulfides, whereas that in the beds above is relatively lean in iron. The ore is in thick veins along well-developed pitches and particularly well-developed flats.

The mine has never been robbed to any extent. A relatively low-grade extension of the ore body continues from the southeast end of the east ore body toward the Kennedy mine.

Lawrence mine (*pl. 1, no. 80*).—The Lawrence mine, in the center of the NW¼ sec. 30, T. 1 N., R. 1 E., was discovered by the Cleveland Mining Co., who found the deposit by drilling about 1912 or 1913. The mine was operated from 1913 to 1917 and has never been reopened. The workings consist of a 150-foot shaft and two parallel stopes spaced 400 feet apart, which trend N. 75° W. and are connected by a drift (pl. 5).

The total production of the mine is probably more than 100,000 tons, and in 1915 it produced 3,171 tons of zinc-lead ore.[54] The volume of water pumped to keep the mine drained was probably large.

The ore body is controlled by pitches, and it flanks a third-order N. 75° W.-trending syncline, which is located along the second-order, northeast-trending Crawford-Martin syncline. The south limb of the ore body is controlled by a south-dipping pitch that at the east end starts to curve toward the north, forming a part of an arcuate nose. The north limb of the ore body is reported to have also a south-dipping pitch, but the report may be in error, as the structural relations of the folds to the ore body suggest a north-dipping pitch.

The ore is deposited in the lower part of the Prosser cherty member of the Galena dolomite and in all beds of the Decorah formation. From this information it can be inferred that the stopes reach a height of at least 40 feet. Apparently much of the ore impregnates the shaly limestones, replaces the dolomites, and cements solution breccias, but some veins of ore are deposited in the main fractures. A considerable amount of mining was done in the disseminated ore of the Guttenberg member.

Cleveland mine (*pl. 1, no. 81*).—The Cleveland mine, in the S½NW¼ sec. 30, T. 1 N., R. 1 E., is developed in a typical arcuate zinc-lead ore body, closed on the east, and trending N. 75° W. (pl. 5). The two limbs are each 1,000 feet long and are separated by 400 feet of unmined core ground. Drilling by the Cleveland Mining Co. about 1909 found the ore body, and operations commenced the following year with the sinking of the shaft to a depth between 150 and 160 feet. The mine was operated until about 1917, probably at a profit.

Above the Cleveland mine workings a substantial tonnage of galena was taken out from shallow small mines in the nineteenth century by the original settlers and by the Crawford Mining Co. This ore occurs in joints and openings in the non-cherty beds of the Galena dolomite. About 1855–60 the Crawford Mining Co. drove a drainage adit about half a mile long, to drain the water from the lower parts of the galena deposits. The northern end of this adit passes over the Cleveland mine workings. The adit was abandoned before being completed, when it was filled by a flood in the Scrabble Creek Valley.

The quantity of ore mined from the Cleveland mine is not known but, from the volume of zinc-lead ore removed, was probably between 250,000 and 500,000 tons. In 1915 the Cleveland mine produced 7,710 tons of ore.[55] It was briefly reopened in February 1942 by Gill Brothers, and an estimated 1,000 tons of 8 percent zinc ore was produced. It was again opened in April 1943 by Baker and Deutman, and further robbing was done; from this operation 1,200 tons of 6 percent zinc ore was mined. Pumping was a serious problem at the mine, but the actual volume of water handled is not known. Some unmined, probably low grade ore may extend for several hundred feet west of the old stopes.

The ore body is controlled by an arcuate pitch that dips to the north on the north limb and to the south on the south limb. The ore body lies on the flanks of a third-order syncline that trends N. 75° W. and lies within the larger Crawford-Martin northeastward-trending syncline. The ore occurs in the Prosser, Ion, and Guttenberg members. In the Prosser much of the ore is in solution breccias or replacements. Ore in the Ion is in veins, mostly in pitches and flats. In the Guttenberg member the ore is partly in viens and to a certain extent is disseminated as impregnations in the shaly beds. Data suggests that considerable oxidation has occurred in the north part of the mine in the upper stopes.

[54] Data provided by C. W. Stoops.

[55] Data provided by C. W. Stoops.

McMillan mine (*pl. 1, no. 82*).—The McMillan mine is in the NE¼SW¼ sec. 31, T. 1 N., R. 1 E. The shaft is 165 feet deep and penetrated the Guttenberg member. Considerable drifting was done in 1914–15 to a number of drill holes, but practically no ore was found. Mining did not prove the existence of the ore body indicated by the drilling, and this failure was reportedly the result of "salted" drill holes. The only evidence of mineralization on the dump is a little iron sulfide and traces of galena and sphalerite. A well-equipped mill and plant were built.

Federal mine (*pl. 1, no. 83*).—The Federal mine (pl. 13), 3 miles southeast of Hazel Green, is approximately 1,000 feet north of the Wisconsin-Illinois State line, in the SW¼SE¼ sec. 32, T. 1 N., R. 1 E. The zinc ore body was first drilled by the Wisconsin Zinc Co. and was mined by them during World War I. Harold Reineke and others reopened it in December 1944 and continued mining until June 1947.

Access to the ore body is gained by an incline that extends 30 degrees downward to the west. At the foot of the incline is the base of a caved shaft that was used during the first period of operation, at the time of World War I.

The mine workings form a nearly complete ellipse with an open end to the east. The stopes are 30 feet high on the south limb except at the easternmost end where they are 12 feet high, and about 50 feet high on the north limb. A haulage drift, northwesterly in trend, connects the two limbs. Two prospect drifts, 100 and 150 feet in length, were driven from the easternmost end of the north limb and from the nose at the west end, respectively. Neither found workable ore. Several drill holes showing zinc and lead ore are about 300 feet to the southeast of the mine workings.

From 1944 until 1947 the mine produced 15,000 tons of 5 percent zinc ore, and its total production of ore is estimated from the size of stopes in excess of 500,000 tons.

The Guttenberg member is the lowest stratigraphic unit mined; it is not reduced in thickness nor is it exceptionally shaly but it has been dolomitized and silicified, especially at the west end of the mine. The succeeding blue and gray strata of the Decorah formation and beds in the Prosser cherty member of the Galena dolomite were mined in some of the stopes on the north limb. The structure and other geological features of the ore body have been described (p. 120).

Tunnel Hill mine (*pl. 1, no. 84*).—This mine, in the SE¼SE¼ sec. 32, T. 1 N., R. 1 E., was in operation about 1905. It is opened by several shafts, adits, and open cuts along an ore body that trends N. 30° W. and has a known length of at least 500 feet (pl. 5). The mine has several levels of workings, in strata ranging from the gray beds of the Decorah formation down into the Quimbys Mill member. The lowest level is in the Quimbys Mill member at a depth of 42 feet. Considerable drifting, but not a great deal of stoping, was done. Nothing is known about the production of this mine.

The ore is in veins along pitches and flats; the pitches strike N. 30° W. and probably dip to the northeast. Above the Quimbys Mill member the ore is mainly smithsonite and galena; in the Quimbys Mill member sphalerite was mined. The ore body is along the east edge of the Kennedy syncline and probably the pitches are controlled by that structure.

Little Dad mine (*pl. 1, no. 85*).—The Little Dad mine is along the west bank of Bull Branch near the northeast corner of the SE¼NW¼ sec. 32, T. 1 N., R. 1 E. The mine operated in 1906, and a large pumping capacity was needed to drain the mine. The extent of the stopes is not known, and ore may remain in the mine.

Three shafts were sunk in a north-south line; the northernmost is about 30 feet south of the north line of the 40 acre tract, the second shaft is 100 feet to the south of the first, and the third shaft about 300 feet south of the second shaft. Sphalerite was found in the northernmost shaft as thin veins in flats in the gray beds of the Decorah formation. This shaft is probably 60 feet deep to the Spechts Ferry member. The second shaft struck only marcasite and went to the top of the Guttenberg member. The third one went into the Spechts Ferry member and has good galena and smithsonite ore on the dump.

Big Dad mine (*pl. 1, no. 86*).—The Big Dad mine is just north of the Little Dad mine, in the NE¼NW¼ sec. 32, T. 1 N., R. 1 E. The mine was opened in April 1903 and operated until sometime after 1906. The northwesternmost of the several shafts (pl. 5) was probably the main hoist shaft. The deposit is in an area of old lead diggings and was found by shaft-sinking. The main hoist shaft, 120 feet deep to the Guttenberg member, was sunk west of the ore body.

A carload test of ore yielded a 30 percent zinc concentrate upon jigging (Telegraph Herald, 1906), but the production of ore is not known. It is not known if the ore body is completely mined out.

The ore occurs as vein sphalerite mainly in the Ion member and is accompanied by considerable marcasite. The ore is mainly in flats in the fracture zones along the west side of the Kennedy syncline. Some of the flats of ore were reported to be as much as 15 inches thick.

Richards or Berg mine (*pl. 1, no. 87*).—The old Richards or Berg lead mine is located on the south side of a small ravine in the northwest corner of the NE¼ sec. 32, T. 1 N., R. 1 E. Stopes extend for about 150 feet south from the shaft and 100 feet northeast from the shaft (pl. 5). The ore is galena accompanied by marcasite, and some of this ore occurs in the Guttenberg member. About 20 prospect holes were drilled in the vicinity and some of these cut lead ore in the Decorah formation.

Rowley mine (pl. 1, no. 88).—The Rowley mine (fig. 84) at Buncombe, Wis., in the S½NW¼ sec. 33, T. 1 N., R. 1 E., is one of the oldest lead-zinc mines in the district. Before 1899 the ore body was worked for galena and smithsonite through an adit, shafts, and shallow workings 30 feet above the Quimbys Mill member. In May 1899 the Bunkum Mining Co. cleaned out the old adit and sank a shaft to the top of the Quimbys Mill member at a depth of 86 feet. Pitches and flats containing zinc ore were found, and the mine was operated until some time early in 1908. Some of the shafts of the old workings are shown in the lower right hand corner of figure 84.

In October 1911 an ore body about 400 feet to the north was opened by the Vinegar Hill Mining Co. and operated by them until January 3, 1913.

While operated by the Vinegar Hill Mining Co., an estimated 100,000 tons of about 6.5 percent zinc ore were produced, and the jig concentrates averaged about 31 percent zinc. A fairly large tonnage of ore was mined by earlier operators. Only a small amount of water was pumped. A description of the earlier workings is given by Bain (1906, p. 84); Dugdale (1900, p. 23–25).

The ore body has two parts curving toward each other, and has a horseshoe-shape at the west end. Only the north limb was mined during the later period of operation, as the ore on the south limb had been oxidized to smithsonite, which was less valuable than sphalerite. The ore body trends eastward, and it lies on the flanks of a third-order syncline of the same trend. The pitches and flats are well developed, the pitches on the north limb dipping to the north and those on the south limb to the south. Owing to the deep oxidation of the sulfide ores, the arcuate part of the ore body at the west end has never been worked.

The primary ore is mainly vein sphalerite, with some galena. The main floor of the mine was generally kept 2 or 3 feet above the Guttenberg member. Much of the ore is in the Prosser and Ion members, but a little ore was mined from the Guttenberg member at the east end of the north limb.

New Occidental mine (pl. 1, no. 89).—This small zinc mine, in the NW¼NE¼NE¼ sec. 34, T. 1 N., R. 1 E., (pl. 5) was operated around 1900 by the Occidental Mining Co. There are two shafts; the older one is about 300 feet northwest of the newer one, which was opened and operated by the Frontier Mining Co. in 1910. The older shaft is said to be 80 feet deep to the Guttenberg member. The newer shaft also went to the Guttenberg member and is about 70 feet deep. Much scattered drilling was done in the vicinity of the mine by the Frontier Mining Co. and the Wisconsin Zinc Co., but results are not known. Neither period of operation produced much ore.

The ore body probably has a N. 45° W. strike and is on the north limb of a local, northeast-trending syncline.

The dump of the northwestern shaft contains abundant pyrite and marcasite, with a little sphalerite, in fragments of the Ion member of the Decorah formation; the dump of the southeastern shaft has vein zinc ore, with considerable marcasite, in the same member but probably not in mineable quantities.

B and C mine (pl. 1, no. 90).—The B and C mine, in the center of the W½SE¼SE¼ sec. 4, T. 1 N., R. 2 E., (pl. 5) was opened about 1904. The Wisconsin Zinc Co. drilled a number of holes in ore on the property in 1909, and operated the mine, possibly during that year. The shaft, which is 33 feet deep, was reopened and recribbed in 1943 by the Coughlin Mining Co. The property had a jig mill, and a small tailings pile remains. Probably the mine produced less than 10,000 tons of zinc ore.

The ore is sphalerite of good grade in veins that probably are controlled by a N. 20° W.-trending pitch that dips toward the northeast. The ore is in the Ion member of the Decorah formation.

Coughlin or Murphy mine (pl. 1, no. 91).—This mine (fig. 84) is in the NW¼SE¼ sec. 4, T. 1 N., R. 2 E. The Murphy mine, the oldest part of the present mine, opened in 1904 when the shaft was sunk. The Coughlin shaft was sunk about 1912, and considerable stoping was done near it in zinc vein ore, rich in iron sulfides, along pitches in the Ion member. The Murphy shaft was reopened in the 1930's by Welch and Hofer, but after a short period of successful mining in the Ion the plant burned down and the mine was closed. The Coughlin shaft was reopened in August 1942 and deepened to 115 feet, or 7 feet below the base of the Quimbys Mill member by the Coughlin Mining Co. (later reorganized as the New Lucky Hit Mining Co.); the mine was operated until June 1946 in the Quimbys Mill member in new workings beneath and beyond the older upper workings. The Lucky Seven Mining Co. continued this mining until November 1946.

From 1942 to 1946 the mine produced about 20,000 tons of zinc concentrate that averaged about 20 percent zinc from an estimated 100,000 tons of ore, which was milled on the property in a gravity mill.

The ore body is rectangular in pattern (fig. 84) and the lower, or main workings, have been mined for a length of almost 2,000 feet, a width of 40 to 80 feet, and an average stope height of 10 feet in the Quimbys Mill member. The upper workings are about 10 feet above the main ones and about 25 feet high in the Ion member. The ore body swings around the end of an anticline, and the pitches dip toward the central anticlinal area. The main structural control in the lower workings are bedding-plane faults in the Quimbys Mill; in the upper workings mineralized reverse faults control the ore body.

In the lower workings the ore fills the bedding-plane faults and the fractures in brecciated Quimbys Mill. Only locally does the ore occur in veins along the reverse faults. The ore in the Quimbys Mill is high grade and contains sphalerite, and some galena, marcasite, and barite. In the overlying Decorah formation the ore in the upper workings is deposited as veins in the well-developed pitches and flats. This ore is low grade and very rich in iron sulfide.

Boyle, Hardy, or Hofer mine (pl. 1, no. 92).—This mine (fig. 85) is in the SW¼NE¼ sec. 4, T. 1 N., R. 2 E. The zinc ore body was originally discovered in the 1890's and was operated until about 1900. The mine was reopened by the Hofer Mining Co. in November 1944 and was operated until July 1947. Until May 1945, the Hofer Mining Co. took up floor in the uppermost or 65-foot level. The shaft was then deepened from 80 feet to 105 feet, to the base of the Quimbys Mill member, and ore was mined in this member until the mine was closed.

From 1944 to July 1947, the Hofer mine produced an estimated 22,000 tons of ore that averaged 5 percent zinc. Very little pumping was necessary. Earlier operations of this mine were noted by Bain (1906, p. 93).

The ore body has a northwesterly trend; it is near the southeast end of the linear syncline that trends N. 65° W. and contains the Paquette and DeRocher mines toward the northwest. This ore body has been mined for a length of 600 feet and, including all the stoped levels, to a height of 55 feet. It is controlled by two outward-dipping reverse fault zones, of which the west zone is the stronger. At the south end the two pitches converge and form a south-facing nose; only the west pitch continues southward and probably is the same pitch as that mined in the Coughlin mine to the south (fig. 84).

The veins of ore in the Decorah and Galena formations contain only a little iron sulfide, and high-grade lead-zinc ore that is deposited along the very well-developed pitches and flats. A top flat of solid smithsonite and galena 3 feet thick partly remains at the roof of the ore body. The ore in the Quimbys Mill member, occurring in a breccia with considerable barite and marcasite, is low grade. No pitches were developed in the Quimbys Mill member; the ore occurs in brecciated zones beneath the base of the pitch zones that cut the overlying beds.

Oakland Level, Brady mine, and McFeeley Level (pl. 1, no. 93).—The Oakland Level, in the SW¼SE¼ sec. 4, T. 1 N., R. 2 E., was operated by the Wisconsin Lead and Zinc Co. during the eighteen nineties, and a considerable tonnage of ore was mined. The level (pl. 5), or mine opened by an adit, has a north trend and has been mined for at least 500 feet north of its adit mouth. The west end of the Coughlin mine, to the north, has cut into the floor of the north end of these old stopes. At its adit mouth the Oakland Level has its floor in basal blue beds of the Decorah formation. Galena, sphalerite, and smithsonite were mined from the Guttenberg, Ion, and locally the Quimbys Mill members.

An old shaft and open cut about 100 feet east of the mouth of the Oakland Level probably is the Brady mine operated by the same company on an extension of the Little Giant mine ore body to the west (pl. 5). The Brady mine, which is in the Ion member, has vein zinc ore of good grade on the dump; it trends N. 60° E.

Southeast from the Oakland Level and Brady mine is the old McFeeley Level, which has a large dump. The mine trends N. 45° E. and is marked at the surface by a line of caved shafts for 550 feet. It was probably also one of the Wisconsin Lead and Zinc Co. mines that operated during the 1890's. The zinc ore is in veins in the Ion member. No data regarding the production from these mines are available.

Little Giant (formerly the "Drybone Diggings") and Galena Level (Butler) mines (pl. 1, nos. 94 and 95).—The Little Giant and Galena Level mines (Kummel, 1895) (Bain, 1906, p. 92) are in the E½SW¼ sec. 4, T. 1 N., R. 2 E. (pl. 5). The Little Giant deposit was discovered in 1839, and was worked for many years as the Drybone Diggings for galena, and later for smithsonite, by shallow shafts and stopes. Some of the first zinc ore shipped from the district was gathered from the dumps of this deposit and sent to La Salle, Ill., for smelting in 1860. The mines were in operation for smithsonite during the eighteen seventies.

In the 1890's the Wisconsin Lead & Zinc Co. reopened these properties on a large scale for smithsonite, sphalerite, and galena. The Drybone Diggings were reactivated as five shallow open pits (pl. 5), the largest or easternmost of which was called the Little Giant mine (fig. 85). In 1890 a drainage adit, Finley's Level, was driven northeast in the Quimbys Mill member beneath the Little Giant open pit. A shaft 40 feet deep was sunk

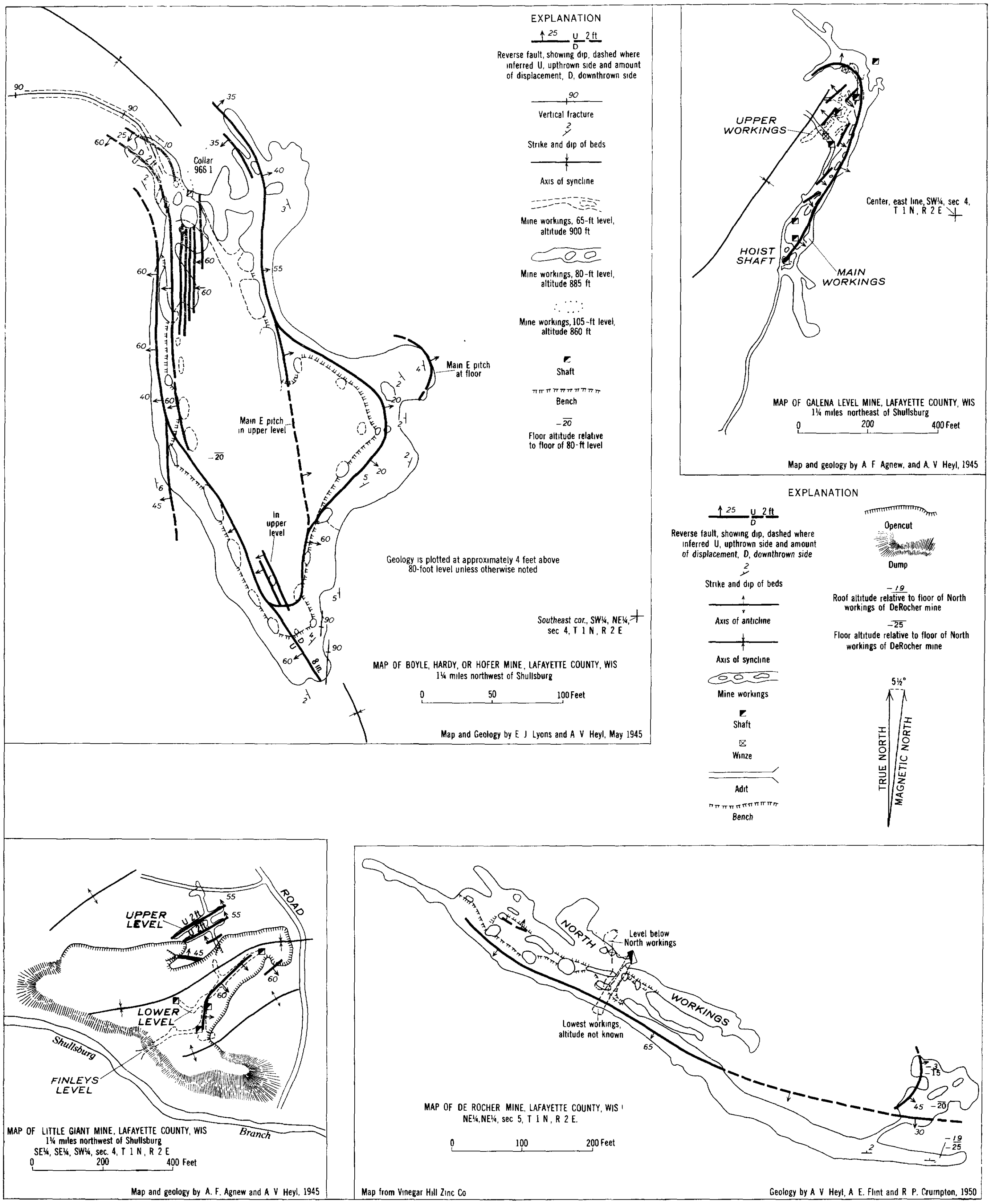


FIGURE 85.—Maps of Boyle (or Hardy or Hofer), Little Giant, Galena Level, and DeRocher mines.

from the floor of the Little Giant open pit through the drainage adit into underlying the McGregor member. Mineable sphalerite ore was penetrated through this entire 40 feet, and much of it was mined. About 1902 a drift was driven N. 15° W. from the north face of the open pit in the lower Ion and zinc carbonate ore was mined from northeast-striking pitches, and sphalerite ore from replacement deposits in beds in the north part of the drift.

In 1945, Mr. and Mrs. Hubbard McNeal of New Diggings, Wis., reopened Finley's Level and mined sulfide zinc ore from it until 1947.

The Wisconsin Lead and Zinc Co. produced both sphalerite and smithsonite during the 1890's from an adit called the Galena Level (fig. 85), which extends northward from the ravine west of the Little Giant mine. Quite probably this adit had been driven many years previously for lead ore and operated as the Butler mine, and many local residents consider it one of the oldest mines in the Shullsburg part of the district, which suggests that the mine was originally opened before 1830.

The Galena Level mine was reopened in 1942 by the Galena Level Mining Co. and was operated by them on a small scale until 1947.

Both mines, the Little Giant and Galena Level, have produced large tonnages of galena and smithsonite ore in the past, and also some sphalerite ore. From 1942 to early 1945 the sphalerite ore produced by the Galena Level mine averaged about 5.5 percent zinc.

The Little Giant ore body is controlled by two pitch zones, one of which follows the northwest pit wall and the other the southeast pit wall (fig. 85). The pitch zone along the north pit wall is composed of four reverse faults that dip between 45° and 55° toward the northwest. A similar but less well developed zone follows along the southeast pit wall, and in the Finley Level, has dips of about 60° toward the southeast. The four other opencuts to the west are controlled by similar eastward- and northeastward-trending pitches.

The Galena Level mine is in an arcuate ore body open toward the south with a N. 20° E. trend that lies within a northeastward-trending and southwest-plunging syncline. The southeast limb of the ore body is controlled by southeast-dipping mineralized pitches. This limb has been mined for 1,000 feet in length and 50 feet in width. At the northeast arcuate nose pitches swing around to the west. Near the nose considerable galena and smithsonite have been mined from the central core area along vertical joints and steep northwest- and southeast-dipping pitches in the Galena dolomite. The ore in the lower stopes is present in veins along well-developed pitches and flats in beds of the Ion, Guttenberg, and Quimbys Mill members. Locally the ore contains considerable galena, barite, and iron sulfides besides the vein zinc. Stalactites of transparent pale-green melanterite and acicular white gypsum crystals coat the mine walls.

Little Bennie mine, McPhee Level, or Moore Level (pl. 1, no. 96).—The Little Bennie mine, in the SW¼ SW¼ sec. 4, T. 1 N., R. 2 E., was originally opened and operated by the Wisconsin Lead and Zinc Co. in the eighteen nineties as the McPhee Level. It was reopened in 1941 by the Little Bennie Mining Co. as the Little Bennie mine, and a little mining was done. Afterwards, some additional work was done by Mr. and Mrs. Hubbard McNeal on a very small scale. Drilling in 1945 at the south end by the Galena Level Mining Co. led to the discovery of some ore in beds of the Quimbys Mill beneath the old workings. This company began mining with a 15-foot shaft sunk in September 1945 and mining continued until 1947.

The mine produced a very small tonnage of 3 percent zinc ore and 63 percent lead concentrate while operated by the Little Bennie Mining Co. in 1941. From September 1945 to August 1947 the small tonnage of ore produced from the Quimbys Mill averaged about 4.5 percent zinc and 0.7 percent lead.

The workings are opened by an adit that has a N. 34° W. trend at its mouth (pl. 5) and the floor of which is at the top of the Guttenberg members. About 400 feet to the north of the adit is a shaft, 80 feet deep into the Guttenberg member that gives access to the north end of the mine workings. The adit "ore body" trends N. 34° W. and is controlled by a pitch that dips 45° to the northeast. A drift connects the adit stopes to the north part of the mine, in which was mined an eastward-trending flat of sphalerite. At the eastern end this heading was turning south and contained good disseminated sphalerite ore when abandoned.

Most of the ore occurs in pitches and flats in the Guttenberg and Ion members; disseminated ore is also in the Guttenberg. The ore in the Quimbys Mill member beneath the new workings developed from the 15-foot shaft cement rock breccias and fills thin bedding-plane partings to form thin flats. Smithsonite and barite are present in the ores in addition to sphalerite.

DeRocher mine (pl. 1, no. 97).—The DeRocher mine (fig. 85) is in the NE¼NE¼ sec. 5, T. 1 N., R. 2 E. After drilling by the Vinegar Hill Zinc Co. and by others, the mine was opened and operated by Mr. Joseph Piquette of Platteville, Wis., from September 1935 to April 1937. The shaft was 90 feet deep, into the Guttenberg member. A very small volume per minute of water was pumped.

The mine was reopened in July 1942 by the Mathey

Mining Co. and operated until November 1942; it was again reopened and operated from April to August 1947 by the Hofer Mining Co.; and once more in March and April 1949 by the S. D. & H. Mining Co. In 1950 the shaft was deepened to the Quimbys Mill member by the Hofer Mining Co., and ore was mined from that zone until August 1951.

In 1942 the operations produced about 1,500 tons of 5 percent zinc ore.[56] In 1947 it yielded approximately 1,500 tons of 7 percent zinc and 1 percent lead ore. Production from the Quimbys Mill run exceeded 5,000 tons of 5 percent zinc and 0.6 percent lead ore. From the size of the stopes the total production of the mine is between 40,000 and 50,000 tons of unsorted ore.

The ore body lies within the same N. 65° W.-trending linear syncline as the Boyle mine to the southeast (pl. 5) and the Paquette mine to the northwest. An upper body of galena was struck 65 feet above the Guttenberg member. The main zinc-lead ore body is in beds that include the Guttenberg and Ion members and the lower part of the Prosser cherty member. The main ore body has a N. 60° W. trend and is controlled by a pitch that follows the southwest side of the ore body and dips southwest. It has been mined for a length of 900 feet and a width of 30 to 100 feet. The ore occurs as veins along the pitches and flats and contains considerable barite, some of which is an early mineral deposited between the vein walls and the first sphalerite, and the rest is late barite filling the central parts of the veins.

Ernest and Myers Level (pl. 1, no. 98).—This very old, large lead mine, in the SW¼ sec. 5, T. 1 N., R. 2 E. (pl. 5), was operated through a 2,300-foot adit driven N. 15° W. from a tributary of Shullsburg Branch. The adit was driven, and lead was mined during the early 1850's and 1860's. The dump, however, contains good vein sphalerite in all the beds from the Quimbys Mill member upward into the gray beds of the Decorah formation. The size of the dump indicates that a large amount of mining was done. It is not known if any zinc ore remains, but it was abundant in the mine and discarded. Whitney gives a good description of the mine (1862, p. 298–301).

Nip and Tuck or Giles mine (pl. 1, no. 99).—The Nip and Tuck mine is a small operation in the SW¼ NW¼ sec. 7, T. 1 N., R. 2 E., just northeast of the Imperial mine (pl. 5). The mine has shafts 300 feet apart. The mine was operated by James Giles on a small scale at intervals between 1938 and 1947 (pl. 5).

The ore body has a N. 35° E. trend and apparently is a continuation of the Imperial ore body. Sphalerite ore cementing dolomitized breccia of the Quimbys Mill occurs at the southwest shaft and, although of a good zinc ore grade, it is also fairly rich in iron sulfide. The northeast shaft contains vein ore on the Ion member and some smithsonite in the lower Prosser. Here the iron sulfide content is very rich, particularly in that part of the ore body mined last.

An old prospect shaft is located 600 feet N. 10° E. of the northeast Giles shaft, the dump of which contains iron sulfide, sphalerite, and smithsonite from the gray beds of the Decorah formation. Very little mining was done here.

An old adit known as the Drum and Phillips mine was driven from Shullsburg Branch 900 feet northwesterly into the hill and it may have intersected an extension of the Giles ore body northeast of the northeast Giles shaft. The ore, smithsonite, galena, and sphalerite, occurs in flats and pitches. A second adit, farther northeast, penetrated no ore.

Helena-Roachdale, Blain and Logan, and Expansion Level mines (pl. 1, nos. 100 and 101).—The Helena-Roachdale mine (pl. 23) is just south of the center of sec. 7, R. 2 E., T. 1 N. The Blain and Logan mine is in a southward branch of this ore body. The Expansion Level is in the northeast party of the ore body.

The Helena mine is one of the oldest large zinc mines in the district and probably the first one to install a large steam gravity mill. The mine was successfully operated from about 1890 to 1898 by the Wisconsin Lead and Zinc Co. During 1897 the Wisconsin Lead and Zinc Co. drilled 41 holes on the property without great success. The Roachdale Mining Co. reopened the mine in January 1942 and operated it until September 1942 when they temporarily shut down. The mine was reopened in May 1943 and mining continued in operation until October 1944 when the surface plant burned down. The plant was rebuilt; so the mine was reopened once more, in August 1945, and continued in operation until the summer of 1946.

The older mine workings form an intricate network of small drifts and stopes, on several levels. The workings opened by the Roachdale Mining Co. have larger stopes. In many parts of the old mine the roof is in such poor condition that rock falls are a serious problem. The mine was opened through several shafts; the Roachdale shaft is 87 feet deep. The Troy shaft to the north is 40 feet deep and the Higney shaft to the east is about 85 feet deep. The Helena Level adit was driven southward from the south side of Shullsburg Branch to the west limb and drains the mine.

The Blain and Logan mine was worked about 1895–1897, probably by the Wisconsin Lead and Zinc Co. The Expansion Level likewise was originally opened by this company during the eighteen nineties, but was

[56] This data and that which follows furnished by the Vinegar Hill Zinc Co.

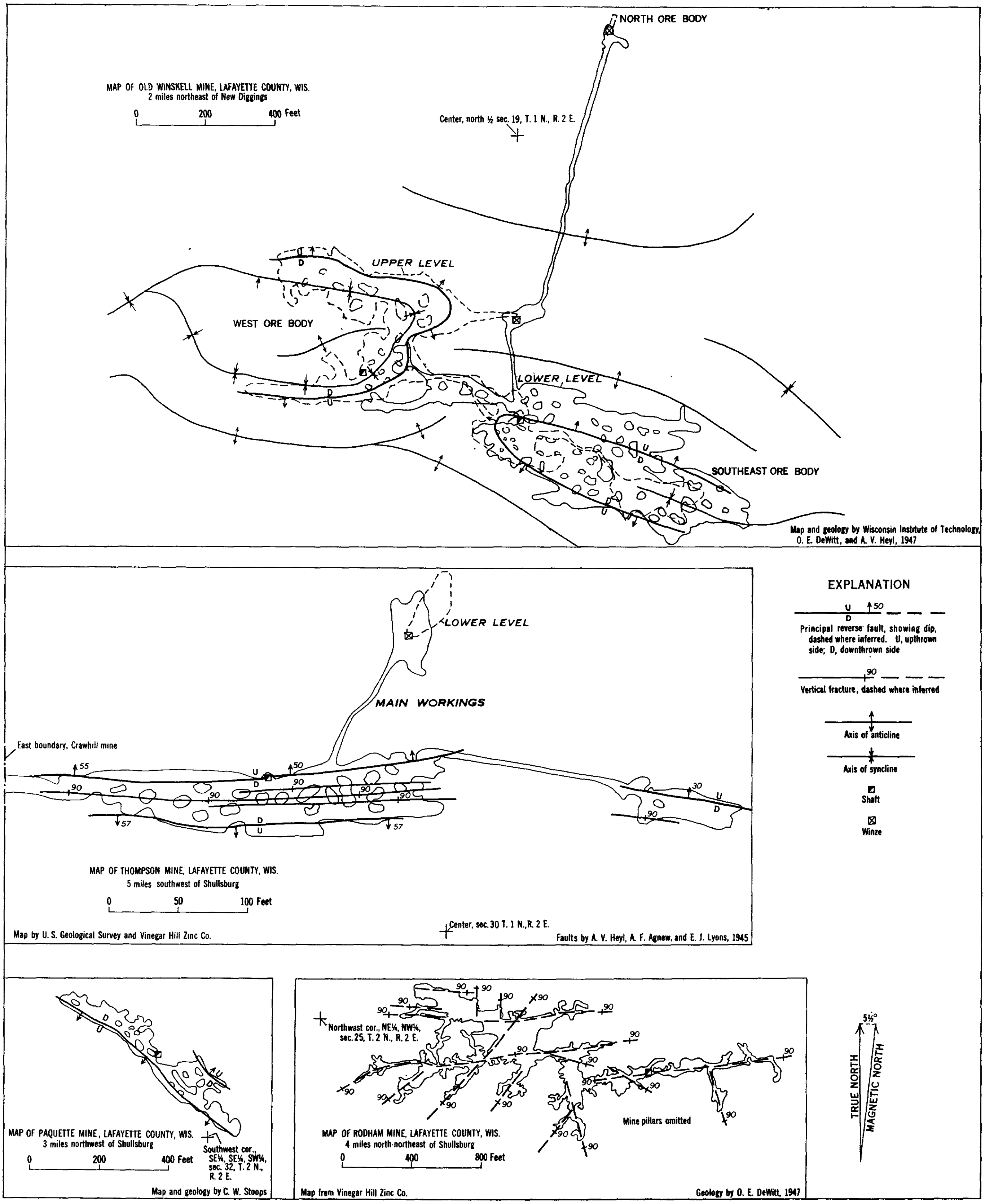


FIGURE 88.—Maps of Old Winskell, Thompson, Paquette, and Rodham mines.

Mulcahy property in the S½, SW¼ sec. 29, T. 1 N., R. 2 E. The ore body was found by drilling in 1950–51 and the mine opened about 1952. It continued to operate during 1954 and possibly into 1955 when it was closed. The ore was milled at the Hancock mill a mile to the east by gravity and flotation. Production is not known, but was probably not more than 100,000 or 200,000 tons. The mine was called the Trewartha (pl. 5) by some, but the Mulcahy by most.

The ore is in veins in pitches and flats in the Decorah formation and Galena dolomite.

Lyne or Winskell No. 4 mine (pl. 1, no. 116).—In 1918 the Oliver Mining Co. drilled in the NW¼NW¼NE¼ sec. 20, T. 1 N., R. 2 E., and located a zinc ore body. Later, additional development was done by C. W. Stoops and by the New Jersey Zinc Co. Mining (fig. 87) was started in March 1941 by the Cuba Mining Co. when a shaft was sunk to a depth of 132 feet, and the mine operated until December 1941.

The mine produced only a small tonnage of ore that yielded 7,000 tons of jig concentrate that averaged 25 percent zinc, and some ore still remains.[61] About 400 gallons of water per minute was pumped.

The ore body is on trend with the Andrews mine to the southwest, and has a N. 20° E. trend. The main part of the mine occurs along the west side of a mineralized zone. The ore is sphalerite veins in the Ion and Guttenberg members, along pitch and flats in the west part of the ore body, and in veins along vertical fractures in the east part.

Calumet and Hecla mine (pl. 1, no. 117).—Several large ore bodies in and near section 22, T. 1 N., R. 2 E., were discovered by drilling by the Calumet and Hecla Consolidated Copper Co. in the years 1947 and 1948 (Ewoldt and Reynolds, 1951, p. 230–231). In 1949 a shaft (pl. 5), equipped with a skip hoist, in the NE¼ SW¼ sec. 22, was sunk 355 feet into the basal Platteville, just above the St. Peter sandstone. In June 1949 long drifts were driven northeastward and southwestward in the Platteville formation to intersect the South Hayden and the Gensler ore bodies, respectively. In 1952 the north drift was extended northward to the North Hayden ore body which lies several hundred feet northeast of the South Hayden ore body. By 1957 this drift had been extended to a total length of about a mile to the Kittoe ore body which lies north of the North Hayden ore body. The south drift had also been extended a few hundred feet to the South Gensler ore body.

The Calumet and Hecla mine is one of the largest producers in the district since 1949 and was still in operation in 1957. The mine is operated with modern equipment and the ore is processed in a 1,200-ton flotation mill. The mill feed of raw ore ranges between 4 and 6 percent zinc. The mine was sold in August 1954 to the Eagle Picher Co., which has continued the operation of it to date (June 1957).

All five ore bodies have easterly trends, but the South Hayden ore body is an arc closed toward the west, and the Gensler ore body is apparently controlled by a north-dipping pitch zone, over 2,600 feet long, that strikes westward and turns south and east at the west end to form an arc. South of the Gensler pitch zone is a 100- to 300-foot wide body of tumbled breccia cemented by sphalerite galena, marcasite, and calcite. The breccia zone is about 100 feet high and is the result of the collapse of the overlying dolomite beds into a void formed by the unusually great solution of the upper Platteville and Decorah before and during ore deposition in the normal core ground part of the ore body. All the beds from the Prosser cherty member downward into the McGregor member contain ore.

The South Hayden ore body is controlled by a step-like arcuate pitch zone (fig. 71) that dips southward in the south limb of the ore body. Breccia and disseminated ore are abundant in the Quimbys Mill and McGregor members. The Platteville and Decorah formations have been thinned by solution but not nearly as much as in the Gensler ore body, and collapse breccias are not nearly as abundant. These formations have been dolomitized in, and for a few hundred feet around, the two ore bodies, but they are still unaltered limestone in the surrounding areas. Barite is a common accessory mineral in the South Hayden ore body.

Blackstone mine.—In 1950 the Vinegar Hill Zinc Co. opened a new zinc-lead mine in the NW¼SE¼ sec. 28, T. 1 N., R. 2 E. (pl. 5), which was still operating in 1957. A vertical shaft more than 300 feet deep starts in the basal Maquoketa shale and has its bottom in the Platteville formation. The mine is operated in three east-trending ore bodies connected by drifts, called the East Blackstone, West Blackstone, and Hancock. The ore is concentrated in a flotation mill about half a mile to the northeast of the mine. In 1955 the American Zinc Co. purchased the mine and mill and continued operations.

Since 1950 the Blackstone mine has been one of the largest producers in the district, and much of the ore is high grade, especially in the Hancock ore body. Much of the ore is in the Platteville formation and contains traces of copper.

Thompson (Fields-Thompson) mine (pl. 1, no. 118).—The Thompson zinc deposit (fig. 88), in the SE¼NW¼ and the SW¼NE¼ sec. 30, T. 1 N., R. 2 E., was drilled and operated by the Fields Mining Co. about 1914. The mine was reopened in October 1943

[61] Data provided by the Cuba Mining Co.

by the Thompson Mining Co. and mining continued until December 1946.

The main ore body has a length of 1,500 feet, a width from 100 to 200 feet, and a height of 50 feet in the Thompson mine, and it has been mined for another 1,000 feet to the west in the Crawhall mine (pl. 5). The partly mined Coulthard ore body has a known length of 500 feet, a width of about 100 feet, a height of 35 feet, and lies 400 feet to the east of the main ore body. About 300 feet to the north of the main ore body is a small ore body that has a general east trend and a length of several hundred feet. A stope was opened in lean ore within the Decorah formation. From this stope a winze 25 feet deep was sunk into ore in the Quimbys Mill, and stopes opened from its bottom to the northeast and east.

The mine has probably produced nearly 500,000 tons of ore that averaged about 8 percent zinc. The pumping necessary to keep the mine drained amounts to 600 gallons of water per minute.

The main ore deposit consists of vein ore in well-developed pitches and flats in the Ion and lower Prosser members. The main and the Coulthard ore bodies have typical eastward-striking linear fracture patterns (fig. 88), and lie within the same east-trending syncline that contains the Crawhall, Fields "Upper Run", Blackstone, and Champion mines to the west (pl. 5) and the Gensler ore body of the Calumet and Hecla mine to the east.

Practically all the central core area between the two pitches in the main Thompson ore body was mineable and has been stoped. The ore occurs here in small veins along flats and minor pitches and fills the fractures of a coarse tectonic breccia. Strong vertical fractures cut through this central core area and trend parallel to the ore body. The richest ore in the mine is along the north pitch zone of the main ore body. The south pitch is a well-developed fracture but contains leaner ore rich in iron sulfides than the north pitch, and therefore it has not been mined at the west end of the mine.

Crawhall mine (pl. 1, no 119).—The Crawhall deposit, in the SW¼NW¼ sec. 30, T. 1 N., R. 2 E., was discovered in drill holes of the Fields Mining Co. about 1912. Operations commenced by driving a 45-degree incline downward to the Guttenberg member. The mine was operated from 1913 to about 1915. The Baker and Meloy Mining Co. reopened it and robbed it in 1946 and 1947. The ore body trends due east (pl. 5), and the stopes are as much as 50 feet high.

Between 500,000 and 1,000,000 tons of ore of a good grade were produced from this mine and the adjacent Thompson mine. Water was pumped at about 600 gallons per minute. Nothing is known of the ore possibilities to the west. Probably low-grade ore remains along the south pitch and in the central core ground.

As the Crawhall mine is in the west part of the same ore body as the main Thompson mine (pl. 5), it is geologically similar in all respects. The ore in both mines contain barite crystal cavities that follow the vein walls and separate sphalerite from the earliest pyrite and marcasite. The crystal cavities are evidence of an early period of barite deposition, when this mineral was deposited as clusters of large platy crystals after the beginning of sulfide deposition, but before the first sphalerite. All of this early barite was redissolved by the ore-bearing solutions before the end of ore deposition.

New Longhorn or Ed Longhorn mine (pl. 1, no 120).—The New Longhorn mine (fig. 89) is in the NW¼NW¼ sec. 31, T. 1 N., R. 2 E., and the adjoining part of sec. 36, T. 1 N., R. 1 E. The original drilling on the property was by the Vinegar Hill Mining Co. in 1917, which located a little ore in one drill hole. The New Jersey Zinc Co. drilled the property in 1924 and discovered the northern ore body, and in further drilling they discovered the middle ore body. Later drilling by the Vinegar Hill Zinc Co. located the Bale or southern ore body to the southwest. The mine was opened in 1926 by the New Jersey Zinc Co. They sank a shaft to the Guttenberg member at a depth of 210 feet. The New Jersey Zinc Co. operated the mine until December 1927, when the company closed all operations in the district. The mine was reopened by the Longhorn Mining Co. in 1929 and, after considerable additional mining on the south ore body, was closed in October 1930.

The production from the mine is not known, but was probably between 50,000 and 100,000 tons of zinc-lead ore. Considerable low-grade ore remains. The volume of water pumped was 800 gallons per minute. This mine was not a particularly successful operation.

The mine is in three linear ore bodies that are connected by drifts. The middle and southern ore bodies were never completely mined (pl. 5). The main structures controlling these ore bodies are shown on figure 171.

The ore is disseminated and in veins and replacement veins, which are deposited in the Decorah and basal part of the Galena formations. In places it is quite high-grade. In the Bale ore body the ore is along vertical fractures, and was too lean to mine profitably.

Annie Walton mine.—The main shaft of this mine is on the southeast corner of the NE¼NE¼ sec. 31, T. 1 N., R. 2 E. The Annie Walton mine is in two ore bodies connected by a north-trending haulage drift (pl. 5). The south ore body, at the shaft, was operated

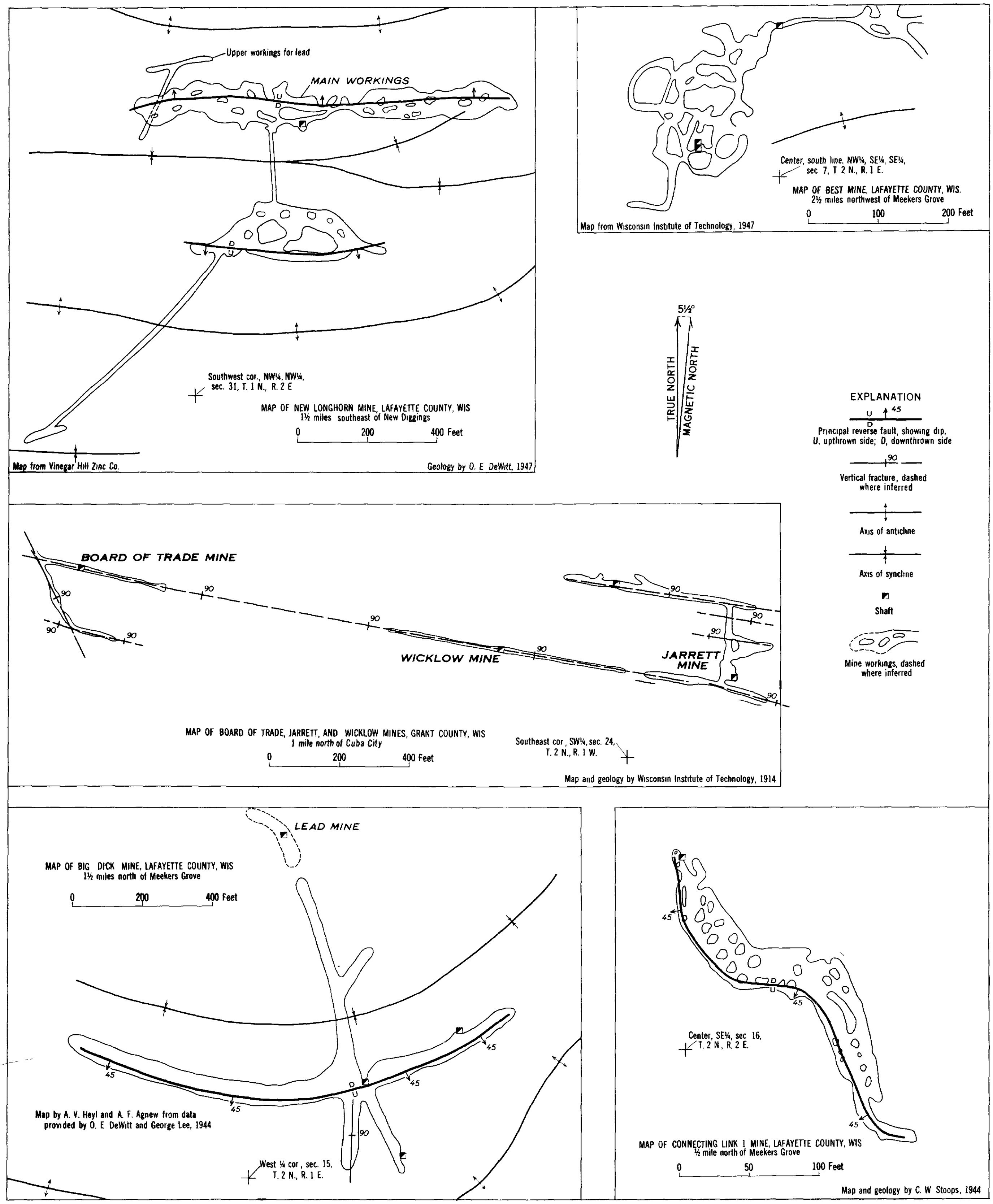


FIGURE 89.—Maps of New Longhorn, Board of Trade, Jarrett, Wicklow, Best, Big Dick, and Connecting Link No. 1 mines.

for lead ore and the north ore body, about 400 feet north of the shaft was operated for zinc. The mine was opened about 1947 by the Little Benny Mining Co. and operated by them until 1949. In 1947 and 1948 lead ore only was produced, but in 1949 some zinc ore was shipped.

In the south ore body galena is in vertical gash-veins in a group of strong northeast-trending joints. The veins are narrow and do not exceed 3 inches in thickness, but are closely spaced. They are in the Prosser cherty member of the Galena dolomite.

The north ore body is sphalerite and abundant pyrite and marcasite in the Prosser cherty member of the Galena dolomite and is a "Middle Run" (Willman, Reynolds, and Herbert, 1946) deposit. Very little ore has been mined from this ore body.

Wilkinson mine (*pl. 1, no. 121*).—The Wilkinson zinc-iron sulfide-lead mine is in the SW¼SE¼ sec. 32, T. 2 N., R. 1 E. The southeast ore body was discovered in drilling in 1908 by the Wilkinson Mining Co.; mining was started in 1909 and continued through 1910. The mine was bought and operated by the Vinegar Hill Mining Co. from 1911 to 1915; a second shaft was sunk about 1,500 feet to the northwest of the original one in the northwest ore body.

The northwest ore body, 750 feet long and 100 feet wide, was developed in the gray beds of the Ion member and in the Prosser beds.

The southeast ore body produced 1,050 tons of "lead ore" (probably concentrate) in 1909, and 53,010 tons of iron sulfide concentrate were produced from 1911 to 1915 inclusive. Zinc ore production from the mine totaled about 150,000 tons.[62] The zinc concentrates produced in the jig mill were low grade, owing to the abundance of iron sulfide, and averaged only 19.5 percent zinc in 1912. The mine rock in the south ore body was so soft and loose that square-set timbering and modified caving mining methods were used.

The ore bodies have typical linear northwest patterns, and lie within a third order syncline that has a N. 30° W. trend. The south ore body, 1,350 feet long and 50 to 150 feet wide, is controlled by two northwest-trending zones of pitches; one dips southwest along the southwest side of the ore body and the other dips northeast along the northeast edge of the ore body.

The ore is in veins along the pitches and flats. Along the northeast pitch zone the ore is almost entirely marcasite and galena, and both products were mined, concentrated separately, and then sold. Along the southwest pitch zone zinc ore was the predominant mineral mined. The ore occurs in the Prosser cherty and Ion dolomite members.

[62] This data and the following provided by the Vinegar Hill Zinc Co.

Lucky Hit (*New Lucky Hit*) *mine* (*pl. 1, no. 122*).—The Lucky Hit mine is in the SW¼SE¼ sec. 33, T. 2 N., R. 2 E. This mine was operated by a Mr. Friend of Pittsburgh, Pa., from 1904 to 1906. The mine was reopened in late 1943 by the New Lucky Hit Mining Co., and the main shaft was deepened to 120 feet. This company was succeeded by the Lucky Seven Mining Co., which operated the mine from August to November 1946.

The mine has four levels, at depths of 22, 45, 75, and 120 feet in the main shaft. The upper two levels were worked for galena and smithsonite, the lower two for sphalerite and galena.

The mine produced probably between 100,000 and 200,000 tons of ore. From 1944 until 1946 about 10,000 tons of 15 percent zinc ore and some lead ore are reported to have been mined. Probably less than 200 gallons of water per minute was pumped to keep the mine drained.

The ore body has a N. 60° W. trend and is controlled by northwest-striking pitches. The two levels contain galena and smithsonite ore in pitches and flats in the Prosser cherty member. The third level is in sphalerite and galena ore in the Decorah.

The fourth level stopes, in November 1944, had been mined for a length of 200 feet, to a height of 10 to 40 feet, and a width of from 20 to 40 feet. The present mine floor, at this level, is in the McGregor limestone member of the Platteville formation, 22 feet below the base of the Quimbys Mill member. The pitches strike eastward and dip to the south. They contain veins of sphalerite, galena, and early and late stage barite. Thick ore-filled flats and breccia ore are associated with the pitches. The stopes are from 10 to 40 feet high in places. The limestone beds of the McGregor, where mineralized by the ore solutions, are altered to a grayish-green shale which is a solution-residue similar to the oil rock shales of the Guttenberg.

Paquette mine (*pl. 1, no. 123*).—The Paquette mine (fig. 88) is in the SE¼SW¼ sec. 32, T. 2 N., R. 2 E. Drilling about 1917 by a Mineral Point company headed by George Huxtable discovered this ore body. In that year the shaft was sunk to a depth of 80 feet. The mine was producing in 1920. In 1922 the shaft had been deepened to 90 feet and work was in progress on a small scale. In 1924 work was still in progress and stoping was being done at a depth of 112 feet, in stopes that range from 10 to 25 feet high. The mine was reopened in 1930 and again about 1935 by other companies, and additional mining was done.

The possibility that ore exists in the Platteville below the present mine floor has not been tested. The quantity of ore mined is not known but probably was not more than 20,000 to 30,000 tons of sphalerite ore. About 100 gallons of water per minute was pumped.

The ore body has a N. 50° W. trend, and lies within a linear N. 65° W.-trending syncline that extends northwest for at least 1½ miles and may connect with a similar linear northwestward-tending syncline that contains the Dall and Vandeventer mines (pl. 3), several miles to the northwest.

The ore occurs in the gray beds of the Ion member and in the Prosser member, and locally in the blue beds of the Ion member. It is found mainly along the southwest pitch zone and in the top flat of the core ground, but only locally along the northeast-dipping pitch. The ore is considerably oxidized and brecciated, and locally the vugs contain large spherical masses of sphalerite. Much barite accompanies the ore, and might possibly be recovered as a byproduct.

Rodham mine (pl. 1, no. 124).—The Rodham mine (fig. 88) is one of the large mines of the district, and is in the N½N½ sec. 25, T. 2 N., R. 2 E. The ore body was discovered by Rodham Brothers about 1909 from outcrops of galena and smithsonite in a small brook. It was opened by them in that year, and considerable galena, sphalerite, and smithsonite were mined until about 1913. The mine was reopened by the Vinegar Hill Mining Co. about 1920 and operated by them until August 1925, and then operated by Rodham and McQuitty until April 1926. The main shaft is 110 feet deep into the upper gray beds of the Ion member.

The Rodham ore body is unusual because it is the largest commercial gash-vein ore deposit, and produced more than 200,000 tons of rich lead and zinc ore that equalled the tonnages produced by many of the larger pitch and flat zinc deposits. The ore is reported to have averaged nearly 10 percent lead and 10 percent zinc. About 1,000 gallons of water per minute was pumped. Despite the fractured nature of the ore body the roof of the mine was good when closed.

The mine is reported to be worked out. Little prospecting has been done in the vicinity to locate similar deposits (1950), despite the fact that the Rodham was one of the most profitable mines in the district. Drilling in 1946 and 1947 located a low-grade ore body rich in iron sulfide in the Decorah and Platteville toward the southeast, near the Milwaukee-Shullsburg mine (Kelly, 1949).

The ore body is about 2,400 feet long, 70 to 600 feet wide, and 12 to 40 feet high and consists of an intersecting network of mineralized joints and openings. Many bodies of ore along the individual joints are only 10 feet wide, but they widen locally to 30 or 100 feet. The main joints controlling the gash veins of the deposit strike N. 80° E., and subsidiary joints strike due north, and from N. 35° E. to N. 50° E. The ore occurs in horizontal openings along the joints. A large cave exists commonly between the roof and the ore, which in places is filled with a soft red clay selvage that contains limonite and smithsonite. Below these caves the sphalerite is in thick veins with abundant galena. Calcite is also abundant and commonly occurs in large, nearly clear crystals. Locally, at intersections of joints, vertical chimneys of ore rich in galena were followed upward nearly to the surface. The ore is mostly in the Prosser member of the Galena formation, but some disseminated sphalerite is found in the gray beds of the Ion member along a prominent shaly layer, at the mine floor.

The Milwaukee-Shullsburg, or Rowe mine (pl. 1, no. 125).—This lead-zinc mine, on the property next east of the Rodham mine, in the W½NW¼ sec. 30, T. 2 N., R. 3 E., was opened and operated by the Milwaukee-Shullsburg Mining Co. from 1917 until the latter part of 1918 when it was closed because the mill burned down. The mine was briefly reopened by the Little Joe Mining Co. in 1945, and a small quantity of high-grade lead ore was mined.

The ore body is small but otherwise similar to that of the Rodham mine to the northwest (p. 130). An old map of the workings shows that the ore body has a general east trend and apparently is controlled by eastward-, northward-, and northwestward-trending vertical joints. The mine workings are 120 feet long and 20 to 40 feet wide. A north prong extends 50 feet north from the east end of the mine, and a southern prong for 40 feet south of the shaft along a southeast-trending joint that intersects with an east-trending joint at its southern end. The ore is galena, sphalerite, and smithsonite, in gash veins along joints, and openings in the Prosser member of the Galena dolomite.

James Rowe lead mine (pl. 1, no. 126).—This lead mine is in the SW¼NE¼ sec. 30, T. 2 N., R. 3 E., east of the Milwaukee-Shullsburg mine and on the same easterly trend. It was first opened by a shaft sometime between 1915 and 1920, and a small amount of mining for lead ore was done. In 1945 it was reopened by the Little Joe Mining Co. and additional lead ore was mined. The mine was shut down owing to pumping difficulties. In 1949 it was operated briefly by J. D. Judd and Son. Mayer and Thiede reopened the mine briefly in the summer of 1951.

Gash veins of galena are in joints and openings in the lower Prosser member of the Galena dolomite, similar to those of the Rodham mine.

Gratiot copper mine.—Several small copper mines are located near Gratiot, Wis. The best known mine is the Gratiot copper mine in the SE¼NW¼ sec. 36, T. 2 N., R. 3 E., about 3½ miles northwest of Gratiot. The workings consist of several shafts and a very small open pit arranged in a northwest line on the southeast bank of a small stream. Some stoping was done, but the stopes were inaccessible when visited. The mine operated in 1908–09 (Cox, 1909), and again in the nineteen thirties. Probably at least a hunderd tons of copper concentrates were produced. In 1914 the Clover Hill Mining Co. shipped about 37 tons of chalcopyrite ore mixed with hematite and sandy clay. This ore, mined in part from the old dumps and the rest from a shaft 45 feet deep, yielded approximately 10,300 pounds of copper and 16 ounces of silver (U. S. Geol. Survey, 1914, pt. 1, p. 123).

The primary ore is chalcopyrite associated with abundant pyrite and marcasite. It fills fractures and replaces Decorah and Quimbys Mill strata partly altered to shale. Near the surface the copper ore is oxidized to tenorite, chalcocite, malachite, and azurite, which form small lumps and nodules. Ore of this type was mined from the open pit.

The ore body has a northwest trend and is deposited within a small northwest-trending syncline. The ore body is possibly controlled by small bedding-plane and reverse faults to form pitches and flats similar to those of the zinc deposits.

Small prospects reported to contain copper ores are near the farm house to the northwest of the Gratiot copper mine. Other small copper mines are in the northeast corner of the SE¼ sec. 21, T. 2 N., R. 3 E., and 2 miles west of South Wayne, Wis., in the S½ sec. 8, T. 1 N., R. 5 E. The South Wayne mines were operated in the eighteen forties and fifties and produced a little ore from vertical veins in the Quimbys Mill member (Percival, 1856, p. 61). The ore bodies trend northeast.

MEEKERS GROVE (JENKINSVILLE) SUBDISTRICT

The Meekers Grove (Jenkinsville) subdistrict (pl. 3) is north of the western part of the Hazel Green-Shullsburg subdistrict and is connected with the latter by a series of galena, barite, and smithsonite deposits worked in the earlier days of mining in the district. A preliminary report and geologic structure map of this area has been published (Heyl, Agnew, and Behre, 1945).

The deposits are not as large as those in the Hazel Green-Shullsburg subdistrict. However, from 1900 to 1930, and again from 1938 to 1951, mining was active. The zinc ore bodies are relatively small but commonly quite rich. In recent years the Depp, Dall, Big Dick, Uniset, and Liberty mines were operated. The area had been inadequately prospected, and geologic indications for other bodies of zinc ore exist.

The stratigraphy is similar to that in the Hazel Green-Shullsburg subdistrict. The uppermost part of the Galena dolomite is eroded. The St. Peter sandstone, exposed locally in the Galena River valley in the southern half of the area, is as much as 55 feet thick and is barren except for local small disseminations of iron sulfide.

The area is strongly deformed and several first- and second-order folds cross it. The largest of these folds is the Meekers Grove anticline, which has an amplitude of as much as 200 feet and extends eastward through the south half of the area. The axis of the anticline rises and falls, and shows a tendency to plunge slightly toward the west (pl. 3). The fold is asymmetric and the north limb is steeper. A first-order syncline lies along the north limb of the anticline. Another fold of importance is a second-order syncline that has a N. 50° W. trend and crosses the area from southeast to northwest, marked by the Vandevanter and Connecting Link mines. Many other folds have east, northeast, and northwest trends, parallel to the larger folds. As elsewhere in the mining district, the smaller folds localize and control the ore deposits and their associated fractures.

Several faults of considerable displacement are known or inferred. Along the steep north limb of the Meekers Grove anticline, east-trending, south-dipping thrusts of 20 to 30 feet displacement exist locally. At the Liberty and Connecting Link mines are shear faults that have north or northwesterly strikes and horizontal displacements of 25 to 200 feet.

The zinc ore occurs generally as veins in well-developed pitches and flats; the pitches having shorter lengths and heighths of only 20 to 40 feet. Some disseminated zinc ore occurs in that part of the area south of the axis of the Meekers Grove anticline and west of the Fever River. Barite is abundant and has been mined in at least three places, and traces of chalcopyrite are common in many of the mines in this part of the area. Gash-vein lead deposits are not very common, and produced a very small proportion of the total ore mined in the subdistrict.

Jarrett or M & D mine (pl. 1, no. 127).—This mine (fig. 89) is in the S½SE¼SW¼ sec. 24, T. 2 N., R. 1 W. The zinc-lead ore body was discovered by drilling by the Jarrett Mining Co. about 1905. Operation began with a shaft approximately 80 feet deep, which was bottomed near the top of the Prosser cherty member of the galena dolomite. The mine was operated from 1908 to about 1913. The mine produced a 33 percent zinc gravity concentrate in 1912.[63]

[63] Data provided by C. W. Stoops.

The ore body is emplaced in three N. 78° W.-trending mineralized joints. The ore occurs in openings about 15 feet wide and high and consists of gash-vein and solution breccia zinc ore rich in galena.

Wicklow or Reliable mine (*pl. 1, no. 128*).—This old zinc-lead mine (fig. 89) is just west of the Jarrett, in the southwest corner of the SW¼SW¼ sec. 24, T. 2 N., R. 1 W. The ore body was discovered about 1890 by drilling. The mine was opened in 1892 and operated until 1894 for lead and some zinc. About 1900 the Wicklow Mining Co. took over the property, deepened the shaft to 160 feet, and mined for a length of 700 feet. The Reliable Mining Co. successfully reopened the mine in 1912 and shipped a 30 percent zinc gravity concentrate,[64] after an unsuccessful attempt in 1908; since then the mine has not been operated. The ore body is in mineralized joints and openings. The main joint strikes N. 80° W. and has been mined along a length of 700 feet, a width of 40 to 80 feet, and a height of 30 feet. A pitch dipping southerly at 45° was noted in the mine floor. Lead ore was mined at depths of 85 and 105 feet, and reports indicate that drill holes cut zinc ore at 210 feet.

Board of Trade or Byrnes lead mine (*pl. 1, no. 129*).—The Board of Trade lead-zinc (fig. 89), approximately 1,200 feet west of the Wicklow mine in the SE¼SE¼ sec. 23, T. 2 N., R. 1 W., was operated prior to 1900 as the Byrnes lead mine, from which a fairly large tonnage of galena was recovered. The property in 1904 was drilled by the Board of Trade Mining Co., who commenced development about 1908, and continued mining at least through 1910.

The mine produced about 1,000 tons of lead concentrate before 1900 and 1,000 tons of 57 percent zinc gravity concentrate in 1909.[65]

The ore body is of the gash-vein type in the Prosser cherty member. The main ore-bearing opening, which has associated small flats, is along the same N. 80° W.-striking joint present in the Wicklow mine to the east. At the west end this joint and a second parallel one 170 feet to the south are crossed by an ore-bearing fracture striking N. 20° W.

Little Dick mine (*pl. 1, no. 130*).—The Little Dick mine is north of the Board of Trade, in the E½NW¼SE¼ sec. 23, T. 2 N., R. 1 W. The zinc deposit was drilled in 1904 by the Little Dick Mining Co., and in 1907 a shaft was sunk to a depth of 53 feet. Later a second shallow shaft was sunk and a small mill erected. The mine was abandoned before 1910.

The ore body is apparently of the gash-vein type in the Prosser cherty member. The Spechts Ferry Shale member is at a depth of 185 feet at the main shaft. Zinc ore is deposited in solution breccia along a mineralized joint that strikes N. 45° W., and is marked at the surface by old lead pits.

The ore is a good grade, and, particularly at the north end, relatively low in iron sulfide. The mine headings probably contained good ore when the mine was abandoned, because the breccia ore was difficult to concentrate to a high grade by jigging.

Best mine (*pl. 1, no. 131*).—The Best mine (fig. 89), in the NW¼SE¼SE¼ sec. 7, T. 2 N., R. 1 E. was located by drilling about 1907 by the Best Mining Co. The mine was operated during 1908 and 1909. The shaft is probably 100 feet deep into the Quimbys Mill member. The ore body has been mined more than 500 feet in approximately a N. 55° E. direction by drifts and narrow stopes.

The ore body curves around the northwest part of a west-plunging nose of an anticline that trends N. 80° E. The sphalerite ore was in clusters of large replacement and impregnated crystals in the Guttenberg member, and is reported to be high grade.

Big Dick mine (*pl. 1, no. 132*).—This mine (fig. 89), in the SW¼NW¼ sec. 15, and the SE¼NE¼ sec. 16, T. 2 N., R. 1 E., is in a southeastward continuation of the Liberty mine ore body (pl. 3). The zinc-lead ore body was discovered by drilling in 1917 or 1918 by the Big Dick Mining Co. and the mine was operated in 1919 and 1920, and again in 1951–54 by a new company also called the Big Dick Mining Co. The main shaft is 128 feet deep, ending in the basal blue beds of the Ion member.

The main branch of the mine has a general easterly trend but is crescent-shaped. This part has stopes 35 to 45 feet high.

The ore averaged 10 percent zinc in 1920 and the jig concentrates were about 30 percent zinc.[66] When abandoned in 1920, the mine contained a large tonnage low-grade ore. The roof in the east part was in poor shape and in danger of caving.

The main branch of the ore body is controlled by an eastward-trending pitch zone that dips about 45 degrees to the south. A transverse ore branch that trends N. 15° W. has been mined north from the shaft for 800 feet. Two other branches extend south from the shaft.

The ore occurs as thick veins of sphalerite along the pitches and flats in the Ion and Prosser members. The ore body is on the southeast flank of a N. 70° W.-trending syncline that contains the Liberty mine to the northwest (pl. 3).

A small lead mine (fig. 89) was opened and operated in the extension of the main north branch of the Big

[64] Data provided by C. W. Stoops.
[65] Data provided by C. W. Stoops.
[66] Data provided by C. W. Stoops.

Dick ore body in 1947 and 1948 and several carloads of galena concentrates were produced.

Connecting Link No. 2 and No. 1 mines (pl. 1, nos. 133 and 134).—The Connecting Link No. 1 mine (fig. 89) is in the E½, SE¼ sec. 16, and the Connecting Link No. 2 mine (fig. 90) is in the SE¼SE¼ sec. 16 and in the SW¼SW¼ sec. 15, T. 2 N., R. 1 E. Both zinc-lead ore bodies were discovered by drilling about 1916 by the Connecting Link Mining Co. The mines operated successfully during 1918, 1919, and 1920.

The shaft of No. 1 mine is 130 feet deep, extending into Guttenberg member, and that of No. 2 mine is 121 feet to the Spechts Ferry member.

The two mines together produced probably between 100,000 and 250,000 tons of zinc-lead ore. Jig concentrate from No. 1 mine averaged 33 percent zinc and from the No. 2 mine about 29 percent zinc.[67] About 120 gallons of water per minute were pumped from No. 2 mine to keep it drained.

Both mines lie on the southwest flank of the N. 40° W.-trending syncline that contains the Dall mine, to the southeast (pl. 3). Most of the main ore bodies are controlled by pitches that strike N. 40° W. and dip to the southwest.

Connecting Link No. 1 mine has been mined to a height of 35–40 feet. The ore body drops toward the southeast, and considerable ore was left below the floor at that end. The sphalerite and galena ore occurs in thick veins along well-developed pitches and flats. Some barite and much pyrite and marcasite accompany the ore. Drilling has extended the No. 1 mine ore body southeastward to about 200 feet due north of the west heading of No. 2 mine where the ore ends against a major fault (pl. 3).

The No. 2 mine ore body is nearly 100 feet wide at the northwest end, where it is abruptly cut off at the mine heading by the same strong marcasite-filled vertical fault that also cuts off the No. 1 mine ore body at its southeast end. To the southeast of the No. 2 mine shaft the ore body splits into two branches that follow vertical fractures. One branch trends N. 85° E. and the other due south. A flat of lead ore 3 to 6 inches thick and about 40 feet wide was mined from the south branch. The eastward-trending branch also mined a flat of zinc ore beneath a vertical fracture, which was rich in galena at the heading. The ore in these mines was rich in galena and iron sulfides, and the abundance of galena in the No. 2 mine probably made it profitable.

Liberty mine (pl. 1, no. 135).—The Liberty mine (pls. 3, 15) is in the center of the NE¼ sec. 16, T. 2 N., R. 1 E. The Liberty Mining Co. opened and operated the mine from February 1943 to February 1946. It was reopened by the Meekers Grove Mining Co. in 1949–50 and again in 1951. The shaft is 131 feet deep.

From 1943 to 1946 from the size of the stopes the mine produced 20,000 tons of jig concentrates that contained an estimated 20 to 25 percent zinc and 1 to 3 percent lead.

The structural geology of the complex arcuate ore body has been described (p. 122). The ore is mainly veins of galena and sphalerite along flats and pitches and vertical faults, and some solution breccia ore in the core area. In the upper levels, abundant galena was accompanied by smithsonite and a little sauconite and greenockite.

Koll mine (pl. 1, no. 136).—The Koll mine in the NW¼NE¼ sec. 16, T. 2 N., R. 1 E., was operated by Joseph Piquette. The ore body trends N. 67° W. and was mined for 310 feet northwest from the shaft and 70 feet east from it (pl. 3). The ore northwest of the shaft is good vein sphalerite occurring in the Ion and Guttenberg members. To the east the ore is very lean.

Lawrence mine (pl. 1, no. 137).—This zinc-lead ore body (pl. 3), near the center of the N½ sec. 16, T. 2 N., R. 1 E., was discovered by drilling by the Lawrence Mining Co. about 1908. Operations began about 1909 with the sinking of the shaft and continued until after 1912. The shaft is about 80 feet deep into the Guttenberg member. In 1912 the mine produced a 20 percent zinc concentrate.[68]

The ore body trends east and has been mined for a length of 600 feet and to a width of 100 feet. It is controlled by an east-striking south-dipping pitch zone. The ore is in veins in the Ion and Guttenberg members. At the east end of the mine the wall rocks are soft, and the ore is too lean to mine.

Uniset or Meekers Grove opencut mine (pl. 1, no. 138).—This mine (pl. 3) is in the SE¼SW¼ sec. 16, T. 2 N., R. 1 E. It was operated as an opencut in 1938 by the Uniset Mining Co. Iron sulfide was the main ore product and sphalerite was a by-product; 29,007 short tons of iron sulfide concentrates were produced.

The ore body, trending N. 20° W., is 500 feet long and 50 to 100 feet wide. The pit is 25 to 30 feet deep and has a 15-foot cover of stream gravel that contains placer deposits of galena. (See also p. 131.)

The ore consists mainly of marcasite and pyrite, and a little sphalerite in thick veins in the blue beds of the Ion member. A northwestward-trending pitch is reported to follow one side of the ore body.

Big Ten mine (pl. 1, no. 139).—The Big Ten mine was an unsuccessful operation in the center of the

[67] Data provided by C. W. Stoops.

[68] Data provided by C. W. Stoops.

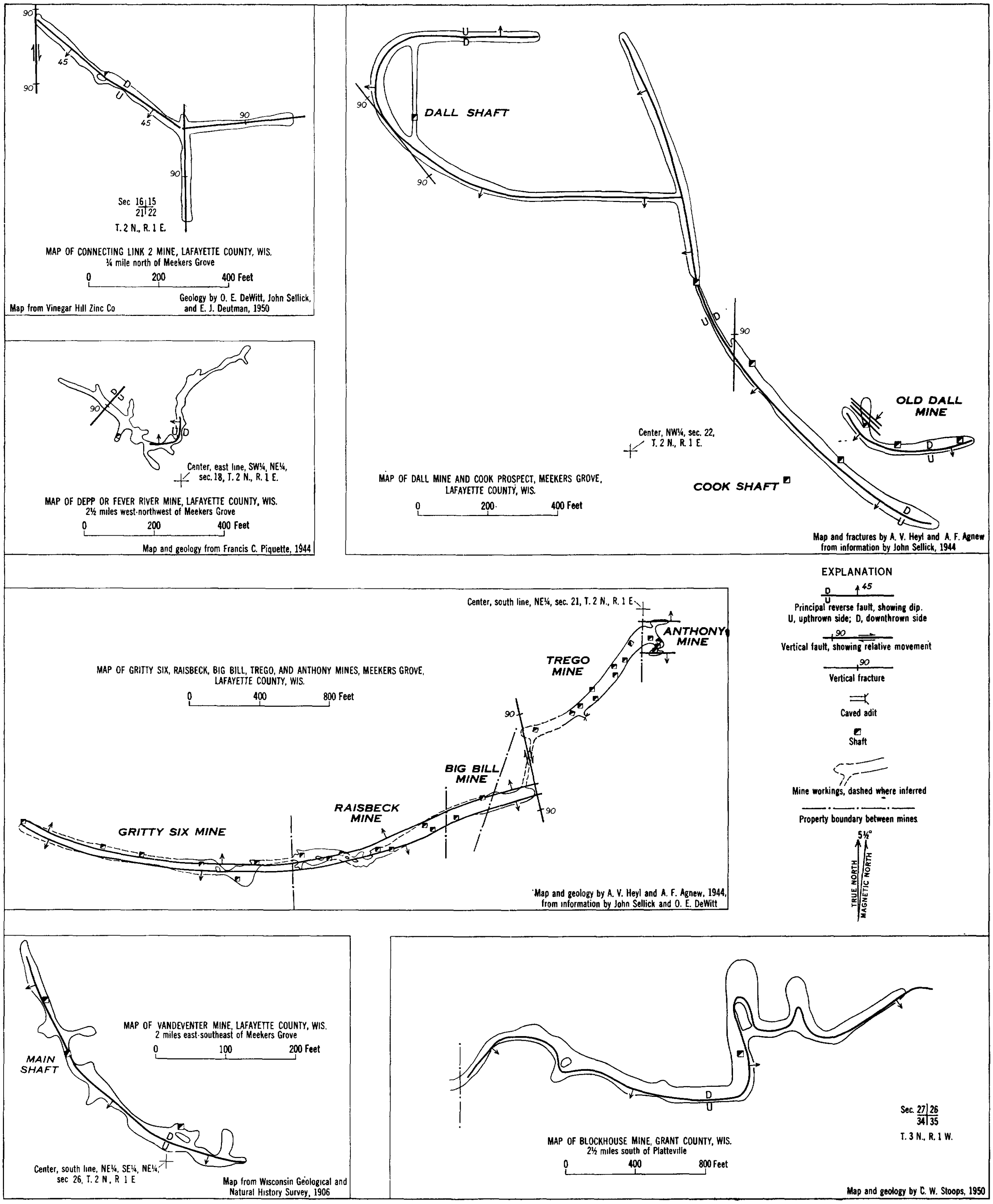


FIGURE 90.—Maps of Connecting Link No. 2, Depp (or Fever River), Gritty Six, Raisbeck, Big Bill, Trego, Anthony, Dall, Vandeventer, and Blockhouse mines and the Cook prospect.

NE¼SW¼ sec. 17, T. 2 N., R. 1 E. (pl. 3). The small ore body was discovered by drilling by the Vinegar Hill Zinc Co. and an attempt was made to mine it during the nineteen thirties when a shaft was sunk to the base of the gray beds of the Ion member at a depth of 85 feet. The wall rock proved to be too soft and rotten to mine and the property was abandoned. Some zinc ore of a good grade, lean in iron sulfide, was found during the shaft sinking.

Masbruch mine (*pl. 1, no. 140*).—The Masbruch mine is in the E½NE¼ sec. 18, T. 2 N., R. 1 E. (pl. 3). The ore body was discovered by drilling by the Vinegar Hill Mining Co. about 1912. The shaft was sunk by that company in late 1912 and early 1913 about 110 feet to the base of the Guttenberg member. Mining commenced in March 1913 and continued until May 1915, when the mine was abandoned. The mine produced 50,000 tons of ore averaging 7.5 percent zinc, and some galena concentrates in 1913 and 1914.[69]

The ore body has a northerly trend and was mined for a length of about 400 feet and a width of 100 feet. The main ore body is in the Ion and Guttenberg members, and the ore occurs as veins of coarsely crystalline sphalerite accompanied by a little marcasite.

Depp (*or Fever River*) *mine* (*pl. 1, no. 141*).—This small but rich zinc-lead mine (fig. 90) is in the S½NE¼ sec. 18, T. 2 N., R. 1 E. The ore body was discovered by drilling by the Fever River Mining Co. about 1907. The shaft was sunk to a depth of 100 feet in late 1907 or early 1908 and the property was operated during that year but then closed. The mine was reopened late in 1941 by the Depp Mining Co. and operated until August 1942. It was briefly reopened from June to October, 1943 by Roy Allen.

The early production from this mine was probably not large. From January to August 1942 the ore is reported to have averaged 12 percent zinc and 0.5 percent lead, and in 1943 ore averaged 6 percent zinc and 0.2 percent lead. Old drill holes are reported to have intersected ore sparsely in the area west of the mine for half a mile.

The ore body has a sharp arcuate nose to the south, and the center of it is controlled by a northward-dipping reverse fault. About 80 feet northwest from the shaft a fracture strikes N. 40° E. across the ore body; it is reported to be a small fault along which the beds on the northwest side were displaced upward.

The ore body averages about 7 feet thick and is localized in the blue beds of the Ion member, although some ore occurs in the Guttenberg beneath. The ore is sphalerite and some galena in flat veins 20 feet wide. The ore is very rich in iron sulfide and the sphalerite occurs mostly within veins of the pyrite and marcasite.

Midway mine (*pl. 1, no. 142*).—The Midway mine is near the center of the S½SW¼SW¼ sec. 19, T. 2 N., R. 1 E. (pl. 3). A shaft was started in 1906 on the basis of supposedly "rich" ore penetrated in five drill holes, and was reportedly sunk to a depth of 145 feet. A large mill was erected in 1908. So far as is known, the mine was never operated. A very small dump near the shaft shows solution-breccia and replacement zinc ore, and considerable quantities of marcasite and calcite, probably from the gray beds of the Ion member or from the Prosser cherty member.

Cuba City mine (*pl. 1, no. 143*).—This small mine is in the northwest corner of the SE¼SW¼ sec. 20, T. 2. N., R. 1 E. (pl. 3). A company was formed in 1906, and the ore body discovered by drilling about that year. A shaft was sunk to a depth of 160 feet into the Quimbys Mill member. The mine was operated in 1909, and it is reported that a considerable tonnage of low-grade zinc ore was shipped; the mine was closed the same year. The ore mined is in the Prosser cherty member and is in a solution breccia with some marcasite and calcite.

Henrietta mine (*pl. 1, no. 144*).—The Henrietta mine is northwest of the Cuba City mine in the center of the S½NW¼SW¼ sec. 20, T. 2 N., R. 1 E. (pl. 3). The lead-iron sulfide-zinc ore body was discovered by drilling about 1907 by the Henrietta Mining Co. A shaft was sunk to a depth of about 108 feet into the Guttenberg member. The mine was in operation in 1909 and 1910. Galena concentrates and iron sulfide concentrates were the principal ores shipped, although some zinc ore was also mined.

The ore is deposited in cavities and fractures of a solution breccia and is very rich in galena and marcasite. Most of it was mined from the Prosser member, but some came from as deep as the Guttenberg member.

It is reported that a drift was started northward toward some reportedly good drill holes in the southeast corner of the SW½NW¼ sec. 20, but was not completed.

Gritty Six mine (*pl. 1, no. 145*).—The Gritty Six mine (fig. 90) is in the center of the SW¼ sec. 21, T. 2 N., R. 1 E. The mine was named by a nucleus of tenacious stockholders who, after considerable initial expense and effort, persisted in prospecting from 1890 to 1897 and, after many unsuccessful attempts, discovered the lead-zinc ore body on October 22, 1897 in a shaft they sank to a depth of 110 feet. The mine was operated continuously from 1898 until the surface plant burned down in 1907, and was a very profitable venture.

[69] Data provided by the Vinegar Hill Zinc Co.

Many unsuccessful attempts have been made since 1907 by drilling to find a westward extension of the ore body.

Abundant barite and a little chalcopyrite, as scattered bands of small crystals in large calcite crystals, accompany the galena and sphalerite ores. The geology of the mine is described by Grant (1903, p. 71).

Raisbeck mine, Buzzards Roost diggings, and Big Bill mine (pl. 1, no. 146).—The old Raisbeck mine (fig. 90) is in the center of the S½ sec. 21, T. 2 N., R. 1 E. The zinc-lead-barite ore body was discovered by shallow shafts sunk for galena in the older Buzzard's Roost lead diggings in 1846. The mine was worked continuously from that time until about 1903, first for lead and then zinc. It was drilled in 1911 by the Vinegar Hill Mining Co. and was reopened in 1912. The Big Bill mine is near the east end of the Raisbeck ore body and was a separate operation for a few years. The mine was again reopened in 1929 and 1930 by William Snow, and galena and barite were mined from the south side. The ore body was described by Percival in 1855 (p. 65, 84), and a map of part of the mine (listed as Trego) is given by Bain in 1906 (p. 90–91, fig. 25). The ore body has been mined for a length of 2,000 feet and a width of 50 to 170 feet; the stopes are 60 feet high.

Though the total production of the mine is probably quite large, only very incomplete figures can be given. In 1875–76, about 700 tons of sphalerite and 40 tons of galena concentrate were mined. In 1912–1913 the Vinegar Hill Mining Co. produced 6,500 tons of ore yielding a 17.5 percent zinc concentrate.[70] About 1,000 tons of barite and 150 tons of galena concentrate were shipped in 1929–30.

Some low-grade zinc ore probably remains in the northeast part of the mine, and some ore in the Quimbys Mill is probably beneath the floor. In addition, a large part of the thick barite flat remains; it contains scattered galena crystals in a ratio of about 6 tons of barite to 1 of galena.

The mine is in a typical linear-east-trending ore body, controlled by outward-dipping, east-trending pitches. The ore body is noted for its richness, and flats of lead, zinc, and barite ore up to 5 feet have been reported. Along the base of the south pitch in the Guttenberg member is a vein of barite 3 to 5 feet thick in a flat that contains scattered galena crystals. In one place this barite vein was cross cut by a drift to the south for more than 40 feet. The zinc ore occurs in all the beds from the Prosser member downward into the Quimbys Mill member, but the main zinc ore occurs in veins along pitches and flats in the blue and gray beds of the Ion member. Some disseminated zinc ore occurs in the Guttenberg member. Lead ore was mined from the Prosser.

Trego-Anthony mines (pl. 1, no. 147).—These mines (fig. 90) are in the N½SE¼ sec. 21, T. 2 N., R. 1 E. The Anthony is at the east end of the Trego mine. The Trego mine was operated from 1901 to 1905 by H. F. Trego, and the Anthony mine was operated about the same time but by another company. The Trego mine had a gravity mill and the zinc concentrates contained 25 percent zinc and 25 percent iron (as pyrite and marcasite). Many shafts and one adit provide access to the mine; the main northeast Trego shaft is 90 feet deep; the main Anthony shaft is 75 feet deep.

At the north end in the Anthony mine the ore body is reportedly controlled by opposing north- and south-dipping pitches having east strikes. To the southwest in the Trego mine the ore occurs as a single flat, and the workings are about 6 feet high, mostly in the Guttenberg member; galena was mined in higher stopes, probably at an earlier time. Smithsonite was discarded. Some barite is present with the ore in the southwestern part of the ore body.

A drift probably connects the Trego mine with the Big Bill part of the Raisbeck mine 300 feet to the south. It is reported that a northward-trending vertical fracture, probably a fault, cuts across the southwest end of the Trego, terminating the ore body and likewise cuts off the east end of the Raisbeck ore body to the south.

Meekers Grove mine (pl. 1, no. 148).—This small zinc mine (pl. 3) is in the NE¼NW¼ sec. 21, T. 2 N., R. 1 E. A 66-foot shaft ending in the Guttenberg member was sunk by the Meekers Grove Mining Co. about 1907. Mining began in the spring of 1909 and continued through 1910, but the mine was flooded twice by high water from the Fever River, and only a little mining was done. The mine was closed probably about 1910 or 1911. The ore body trends N. 85° W. and lies within a local northeast-trending syncline. The ore occurs in the Ion and Guttenberg members and is vein and some disseminated sphalerite, and a little marcasite.

Dall mine and Cook prospect (pl. 1, no. 149).—The Dall mine (fig. 90) is in the N½NW¼ sec. 22 T. 2 N., R. 1 E. The Cook is an unsuccessful prospect at the south edge of the Dall. The Old Dall ore body was discovered by the Dall Lead and Zinc Co. about 1903 by drilling. The Old Dall mine was opened in 1904 by 3 shafts, two of which are 120 and 130 feet deep. A good description of the mine is given by Bain (1906, p. 91–92). The main Dall ore body was subsequently discovered. The Dall mine was opened about 1905 and operated from that time until 1911, and was very successful.

The Old Dall mine was reopened in 1950 by the Meek-

[70] Data provided by the Vinegar Hill Zinc Co.

ers Grove Mining Co. and operated at intervals until about 1952. Much of the ore came from the east heading of the mine.

The production from the Dall mines is not known but was undoubtedly large, probably between 200,000 and 500,000 tons of ore. The plant consisted of a large jig mill, roaster, and magnetic separator. So far as is known, the mine has not been robbed. Low grade ore remained east of the Old Dall mine in 1950 and southeast of the main Dall mine. Additional ore possibly remains in the Quimbys Mill member and in other strata of the Platteville formation beneath the mine floor.

The Dall ore bodies lie within the second-order northwest syncline that contains the Connecting Link No. 1 and No. 2 and Vandeventer mines, at its intersection with northeast-trending folds.

The ore bodies occur in the Decorah formation and lower part of the Prosser cherty member and consist mainly of vein ore along well-developed pitches and flats. The ore in the Old Dall mine is disseminated. The pitches do not flatten into the Spechts Ferry shale member but are reported to continue downward into the Quimbys Mill member. At the southeast end of the main Dall mine, east of the Cook shaft, vein ore gave way to solution-breccia ore, and the southeast heading was abandoned. At the northwest end of the northwest-trending ore body run, and at the east end of the north limb of the arcuate ore run, the ore deposit contained large quantities of iron sulfides so that these headings also were abandoned.

Vandeventer mine (pl. 1, no. 150.)—This small rich zinc mine (fig. 90) in the SE¼NE¼ sec. 26, T. 2 N., R. 1 E., was discovered by the Vandeventer Lead and Zinc Co. in 1907, and was operated by that company until 1912, when it was leased by a Mr. Fox who robbed the mine until 1913. The main shaft is about 30 feet deep. A 100-ton jig mill was put in operation in 1908 and a roaster and magnetic separator in 1909.

The mine was very profitable while rich ore was mined during 1907 and 1908, but was much less profitable during the later years of operation when the leaner ore high in iron sulfide was produced. The mine produced a small tonnage of very rich ore.

The ore body trends N. 40° W. and lies on the southwest flank of the linear northwest-trending syncline that contains the Dall and Connecting Link mines to the northwest. It is controlled by a pitch zone that strikes N. 40° W. and dips southwest, and associated flats. The ore body has a length of 500 feet, a width of 20 to 30 feet, and a height of 25 feet. The sphalerite ore in veins up to several feet thick is found in the Ion and Guttenberg members and is accompanied by veins of marcasite. The richest ore is along the main pitch in the blue beds.

A large tonnage of low-grade zinc ore rich in iron pyrite is reported to remain in the mine. Neither the top nor the bottom of the main ore-bearing pitch was reached, and therefore ore probably exists above and below the present workings. Some good ore was located by the company in drill holes about 600 feet northwest of the mine (fig. 17) and the dump of a prospect shaft across the road southeast from the mine contains similar ore. A prospect shaft 1,500 feet northwest of the mine shows abundant iron sulfide with only a little zinc sulfide on the dump.

Rico mine (pl. 1, no. 151).—The Rico zinc deposit is in the S½SE¼SW¼ sec. 28, T. 2 N., R. 1 E. (pl. 3) and was discovered by drilling about 1906 by the Rico Mining Co. That company sank a shaft 20 feet deep, which was later deepened to about 73 feet. The company erected a 50-ton jig mill but possibly this plant was never used. The mine was operated for only a short time and was closed because of the disseminated nature of the ore, which made gravity milling difficult. The company passed out of existence about 1909.

A little stoping and drifting were done for 100 feet to the south and west of the shaft. Apparently some drifting was also done in a deeper zone in the McGregor, but without success.

The mine dump is very rich in disseminated sphalerite from the Guttenberg and Spechts Ferry strata. There is practically no iron sulfide in the ore. The mine is said to have a pitch that strikes southeast and dips southwest.

The Eagle zinc prospect to the south across the road has similar ore in the gray beds of the Ion member, but it is rich in limonite. It was abandoned also, owing to difficulties in milling the ore.

Pittsburg mine (pl. 1, no. 152).—This small mine is in the W½SE¼ sec. 28, T. 2 N., R. 1 E. (pl. 3). The zinc ore body was discovered in churn drill holes put down by the Pittsburg Lead and Zinc Co. about 1906. It was operated at intervals until it was closed about June 1920. The ore ranged between 25 and 30 percent zinc (Telegraph Herald, 1907). The main shaft is 50 feet deep, to the Guttenberg member. The south shaft is said to have reached the St. Peter sandstone at 100 feet. A jig mill was erected in May 1906.

Stopes that are 30 feet wide extend east and west of the north shaft at a depth of 40 feet. From these stopes disseminated sphalerite was mined in the Guttenberg member. Similar ore also occurs beneath in the Quimbys Mill member. A weak pitch that strikes east dips to the north. At a depth of 75 feet in the south shaft a drift was extended 75 feet to the northwest, where it penetrated a large cavity that trends northeast in the

McGregor member of the Platteville formation. The cavity, 30 feet high and 20 feet wide, was filled with blue clay and disseminated crystals of sphalerite. A fracture that is 18 inches wide and filled with similar clay and ore is reported to continue downward into the St. Peter sandstone. Blue clay of the Glenwood shale member may have been squeezed up along the fracture to form this unusual clay mass.

In earlier years much smithsonite was mined from small opencuts north and east of the Pittsburg mine, and galena was taken at earlier periods from small shafts in the vicinity, and from lead placers in the valley to the east of these opencuts.

Roosevelt mine (*pl. 1, no. 153*).—This deposit, in the NE¼SW¼ sec. 28, T. 2 N., R. 1 E. (pl. 3), was discovered by the Roosevelt Mining Co. about 1905. By 1906 the company had erected a 50-ton jig mill and installed a Trego roaster. The mine was operated until about 1907 and then shut down until 1910, when it was briefly reopened. The ore body apparently has a northwest trend and was mined for 500 feet northwest and for an equal distance southeast from the shaft. The stopes are 15 feet high, but not wide.

The zinc ore body is controlled by a pitch that dips to the southwest and is in veins that are rich in barite and partly oxidized marcasite in the Ion member and Prosser cherty member.

East of the Roosevelt shaft is a large open cut in the lower *Receptaculites* beds of the Prosser cherty member that was mined for smithsonite at some earlier time. In the floor of this cut are several shafts alined easterly. The ore body in these shafts is reported to trend northwest and contains a northwest-trending pitch. The pitch dips to the southwest, and contains sphalerite and variable quantities of barite in a vein up to 7 inches wide. The small mine dumps of these shafts are very rich in ore. An attempt was made early in 1944 to reopen one of these shafts, but the venture was abandoned before completion. The rich ore in these shafts and the large amount of smithsonite mined from the overlying beds makes this prospect an interesting one. The small dumps of the shafts indicate that only a little ore was mined.

James and Little Elm mines (*fig. 1, no. 154*).—The James and Little Elm mines are in the center of the NW¼ sec. 28, T. 2 N., R. 1 E. (pl. 3). These small mines were started on adjoining properties about 1903, and were operated for only a short time. There are at least nine shafts, most of which are shallow and have only galena and barite on the dumps. The main James mine shaft went into the Ion member; smithsonite was mined from the Prosser above. About 1,000 tons of smithsonite remains on the mine dump (1952). The ore body trends northwest and lies within a well-defined third-order northwest-trending syncline that overlaps the first-order northeast-trending Meekers Grove anticline very near its coast.

Pine Tree mine (*fig. 1, no. 155*).—The Pine Tree mine, in the southeast corner of sec. 29, T. 2 N., R. 1 E., was operated briefly by the Pine Tree Mining Co., in 1907–08. The shaft is about 92 feet deep. The ore body, disseminated in the Guttenberg and Spechts Ferry members,[71] is 70 feet wide and was stoped for 70 feet northwest from the shaft. It is reported that this disseminated ore body is between 24 and 26 feet thick and contains 6 to 18 percent zinc ore, which has also considerable galena. The mine was closed when it was involved in litigation in 1908.

Baxter mine (*pl. 1, no. 156*).—The Baxter mine (fig. 91) is in the southeast corner of the NW¼NE¼ sec. 29, T. 2 N., R. 1 E. The ore body was discovered in the latter part of 1904 by the Baxter Mining Co.'s drilling. the mine was operated until about 1912. The main shaft is 120 feet deep.

The ore body was mined on 4 levels, 50, 70, 80, and 100 feet from the surface. Some galena was mined from the 50-foot level in the Prosser cherty member. The main workings are at 70 and 80 feet. The thickness of the ore is 14–15 feet, and it has been mined to widths of 150 feet. The 70-foot level was mined 320 feet west from the main shaft in the basal beds of the Prosser, and the 80-foot level for a distance of 700 feet in a northwest-southeast direction in the lower gray beds of the Ion. The 100-foot level is a drift in the Spechts Ferry member for 100 feet east of the shaft.

The mine was a successful operation owing to the richness of the ore, despite the disseminated type of ore. In 1910 the mine was shipping two or three carloads of zinc concentrate per week. In 1912 the mine shipped a jig concentrate averaging about 45 percent zinc.[72] The total production of the mine is probably between 50,000 and 100,000 tons of ore.

The ore in the 70-foot level is disseminated in a bedded replacement deposit. At the west end three vertical joints strike northward and the beds dip westward and at the east end of the level the beds dip eastward. The eastern part of the 80-foot level follows a gentle syncline that trends N. 35° W., and this part of the ore body is controlled by a pitch zone that strikes northwest and dips southwest. Bedded replacements, and many small veinlets and vugs are deposited in the Ion member in the footwall side of the pitch zone. The

[71] This description, which was taken from old records of the Wisconsin Geological and Natural History Survey, does not check with the material on the dump, which shows solution breccia zinc ore in the basal beds of the Prosser member of the Galena dolomite.

[72] Data provided by C. W. Stoops.

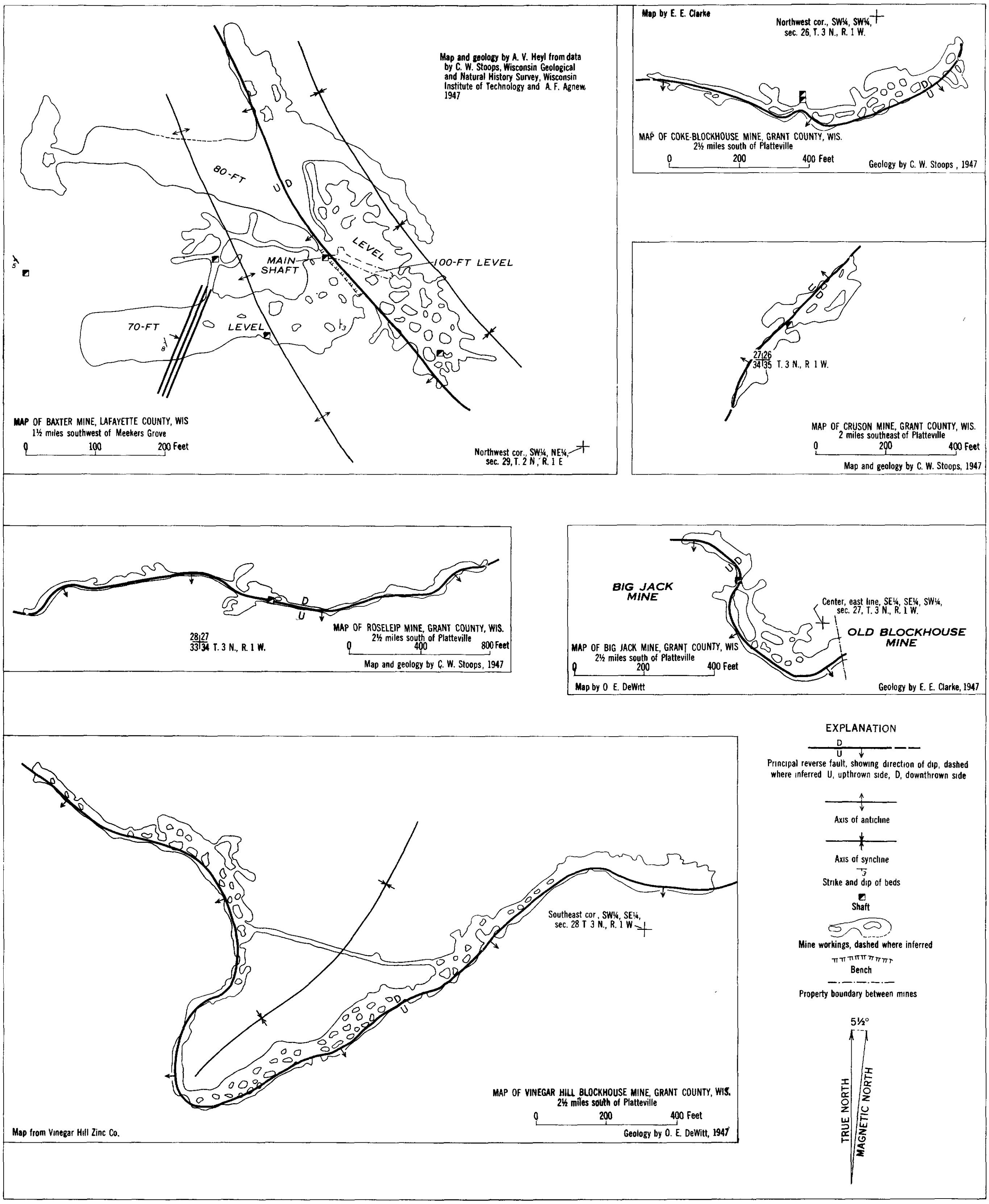


FIGURE 91.—Maps of Baxter, Goke-Blockhouse, Cruson, Big Jack, Roseleip, and Vinegar Hill Blockhouse mines.

ore is remarkably low in iron sulfides, and contains small quantities of copper in the form of chalcopyrite.

Porter barite mines.—The two barite mines of the Porter Mining Co. are located in the NE¼NW¼ sec. 34, and the NE¼NE¼ sec. 33, T. 2 N., R. 1 E., on the east and west sides of the Galena River, 2 miles south of Meekers Grove. The mines were opened by the company in 1919 and produced barite until 1921, and probably again from 1923 to about 1930. They are the only two mines known to have been operated for barite alone in the district.

The larger of the Porter mines is in sec. 34. It is in a barite ore body that trends northward. The ore is in the lower beds of the Prosser cherty member and the Ion member of the Decorah formation. The structure of the deposit is not known but is probably of the pitch and flat type. The barite is coarsely crystallized white masses that fill fractures and replace the wall rocks. A little galena is disseminated in the barite as coarse euhedral crystals.

The smaller of the two Porter mines is in sec. 33. Barite was mined from shallow workings in the Decorah formation. The trend of the deposit is not known, but otherwise it is geologically similar to the other Porter mine.

Similar barite deposits were noted in the vicinity of these mines, especially to the south towards Leadmine.

BIG PATCH SUBDISTRICT

This small and relatively less-important subdistrict lies northwest of the Meekers Grove subdistrict and south of the Platteville subdistrict (pl. 1).

In the nineteenth century the lead deposits of this area were of considerable importance. The largest discovery, from which the name of Big Patch[73] is derived, was a residual flat of galena 18 feet wide and 3 feet thick lying on the surface of bed rock (Whitney, 1862, p. 276–278). In one day $1,500 worth of lead was mined from this deposit.

Between the discovery date (June 1828) and 1843 more than 4,226 tons of galena concentrates were mined from the area. The deposits were abandoned during the eighteen fifties and eighteen sixties, but were reopened on a smaller scale in the eighteen seventies, and mining continued for lead and later for zinc into the early nineteen hundreds.

Zinc deposits, though fairly widely prospected, were not mined to any extent except in two parts of the subdistrict. All known workable deposits occur in the Galena dolomite and Decorah formation, but the deeper strata have not been thoroughly prospected.

[73] The term "patch" is an old lead miners' term used for any area of shallow lead deposits, either residual in the soil, or in intersecting closely spaced joints that have irregular trends.

The stratigraphy is similar to that of the adjoining areas in the central part of the district except that the Spechts Ferry member is between 2 and 3 feet thick, somewhat thicker than to the south and east, and the Quimbys Mill member is only 4 to 5 feet thick, considerably thinner than in the Meekers Grove subdistrict to the southeast.

The area has been moderately deformed, and contains many gentle folds that trend northeast and northwest, and have amplitudes of 30 to 70 feet (Hotchkiss and Steidtmann, 1909, pl. 2).

Beloit-Elmo mine (pl. 1, no. 157).—This zinc-lead mine is in the SE¼SW¼ sec. 2, T. 2 N., R. 1 W. The ore body was discovered by drilling by the Beloit-Elmo Mining Co. about 1908. A shaft was sunk to a depth of 100 feet in 1909, and the mine operated until about 1911, when it was closed because of high operating and pumping costs owing to inefficient equipment. In 1949, A. V. Austermann attempted to reopen the mine, but was unable to drain the water from it.

The ore body is of the gash-vein type and has a general N. 80° W. trend. It was mined about 400 feet east and 200 feet west from the shaft in the Prosser cherty member. The ore is pale yellow sphalerite, with very little iron sulfide, which occurs in disseminated and solution-breccia deposits in an opening along the mineralized joint. Galena locally accompanies the sphalerite.

The west heading of the mine is still in ore and is rich in galena, and the east heading is reported to contain a mineable face of disseminated sphalerite ore lean in marcasite.

Black Hawk, Spink, Big Patch mines (pl. 1, no. 158).—The Black Hawk mine is in the NE¼NE¼ sec. 10, T. 2 N., R. 1 W. Mining commenced about 1904 with the sinking of a shaft 153 feet deep. Attempts at mining were made until about 1909 when the property was finally abandoned. The zinc ore occurs in the gray beds of the Decorah formation. Mining was done in a circular area that extends northwest, north, and north-northeast from the shaft. The operation was a failure because the ore was lean, the royalty excessive, and the mill too costly.

The Spink and Big Patch mines are about a quarter of a mile to the southwest. The Spink mine was operated on a shallow (about 50 feet deep) disseminated zinc ore body along a joint that strikes N. 70° W. in the Galena formation. The Big Patch mine, farther south across the road, was a lead mine worked in 1899–1900, apparently successfully.

Peaceful Valley mine (pl. 1, no. 159).—The Peaceful Valley mine in the SW¼SW¼ sec. 5, T. 2 N., R. 1 E., is in an isolated ore body north of the Meekers

Grove subdistrict. The mine was opened and operated about 1912, and was closed when the pumps were destroyed by accident. In 1912 a 58 percent zinc concentrate was shipped,[74] which probably had been roasted and then further concentrated by a magnetic separator.

The ore body is reported to be large and irregular in shape. The workings are said to extend westward from the shaft and then curve around to the north and east back to the shaft. The ore is sphalerite very rich in iron sulfide.

Lyght mine (*pl. 1, no. 191*).—The Lyght mine is in the SE¼SE¼ sec. 34, T. 3 N., R. 1 W. The ore body was discovered by drilling about 1908. A shaft was sunk to a depth of about 100 feet by the Lyght Mining Co., into the Guttenberg member, and the mine was operated during 1909–10. The ore body has a general N. 70° W. trend. The main workings, in the Prosser, are 30 feet wide, 7 feet high, and extend 100 feet west from the shaft; the ore was in veins. A lower level, developed in the Guttenberg member, was disseminated sphalerite. Iron sulfide content is excessive. The mine is reported to have been exceedingly unsafe, and when it operated, small falls of rock were common.

PLATTEVILLE SUBDISTRICT

The Platteville subdistrict (pl. 1) is one of the large old lead mining areas which later became an important zinc producing area. Many productive zinc mines were operated within the city of Platteville, in the south part of Platteville township along the "Blockhouse Range" and at the site of "Toadville" west of U. S. highway 151, and a few at the west side of the township in "Whig Patch." Scattered lead diggings and zinc prospects connect the Platteville subdistrict with the Big Patch subdistrict to the south, with the Potosi subdistrict to the west, with the Strawberry Grove area beyond Ipswich and Elk Grove to the southeast, and with the important subdistricts of the northern part of the district to the northeast.

Good descriptions of older mines in the Platteville subdistrict may be found in the reports by Whitney (1862, p. 321–326), Strong (1877, p. 744–745), and Bain (1906, p. 93–98).

Discovery of lead in the area was made in 1827 by a Mr. Metcalf. Between 1827 and 1843 about 14,800 tons of lead concentrate was produced. Between 1862 and 1876 about 12,550 tons of lead metal was smelted in the furnaces of the area.

The strata of the subdistrict are of normal thickness except: (1) the Specht's Ferry member is about 2 feet thick, (2) the Quimbys Mill member is 2 to 4 feet thick.

Like the Big Patch subdistrict to the south, the rocks in the vicinity of Platteville are moderately deformed. A gentle, open fold, the first-order Platteville syncline, passes eastward through the subdistrict (fig. 23), and most of the zinc ore bodies lie within this general basin area. South of this structure is a parallel, low, broad anticline, along the north flank of which are located the ore bodies of the Blockhouse Range. The smaller folds have east, northeast, and less commonly northwest trends. Toward the north the beds rise gradually to the crest of the Mineral Point anticline, about 6 miles away.

A major fault, the Capitola, is exposed on both sides of the Little Platte River in the N½SE¼ sec. 18, T. 3 N., R. 1 W. (pl. 8). The fractured zone, about 100 feet wide, trends N. 80° E.; the Capitola fault has the well-developed drag characteristics of a reverse fault. The beds on the south side of this fault have moved upward 25 or 30 feet relative to those on the north side, bringing the topmost beds of the St. Peter sandstone contiguous with the McGregor member of the Platteville formation.

The workable sphalerite deposits occur in the Galena dolomite and the Decorah formation. Some galena, but little zinc ore, has been mined from the underlying Platteville formation.

The Platteville, Decorah, and Galena formations, and the St. Peter sandstone are exposed in the subdistrict. In the east part of the subdistrict zinc ore is found in veins along pitches and flats. West of Platteville and at the west end of the Blockhouse Range the ore bodies are largely disseminated; sphalerite crystals impregnate and replace the Guttenberg member and the blue beds of the Decorah formation. In this west part the inclined fractures are only rarely mineralized.

BLOCKHOUSE RANGE

The Blockhouse Range, extending almost 5 miles, is one of the longest lines of zinc-lead ore bodies in the district. It extends westward in the S½ secs. 26, 27, 28, 29, and 30, T. 3 N., R. 1. W. and the NE¼ sec. 36, T. 3 N., R. 2 W. (pl. 1), and it is practically one continuous ore body, with lean parts in between the richer mined parts. The general trend of the range is due east except at the west end near the site of the former lead mining village of Toadville, where it turns toward the southwest. Individual ore bodies lie on this general trend but in places show remarkable loops and bends as they follow the local structures. In most places they are controlled by an apparently continuous pitch zone that dips toward the south except in local loops.

The mines of the Blockhouse Range produced a good grade of ore, and for the most part they were successful

[74] Data provided by C. W. Stoops.

operations. About 1,500,000 tons of ore was mined from all of the mines in this range. Much of the mineable ore has been nearly worked out, and all the mines are closed at present (1957). The Weigle mine, about 1 mile east of the main range (pl. 1, no. 192), may be an extension of the range.

The mines of the Blockhouse Range are described on the following pages from east to west.

Weigle mine (pl. 1, no. 192).—The Weigle mine is in the NE¼NW¼ sec. 36, T. 3 N., R. 1 W., and may be on the east extension of the Blockhouse Range. The zinc ore body was discovered about 1907 by the Weigle Mining Co., and was later drilled by Standard Zinc Co. A shaft was sunk into the Prosser member during 1908, and mining started in this shallow ore body. The mine was abandoned about 1910 owing to the low grade of the ore shipped, and to caving of the walls and roof. The ore body has a general east trend. Nearly all mining was done east of the shaft for 170 feet, to a width of 80 feet.

Considerable money was lost by this operation. The total production from the mine was probably not more than 2,000 tons zinc ore. A jig mill was installed and operated on the property. A small volume of water had to be pumped to drain the mine.

The ore cements a coarse, loose breccia near north-striking controlling fractures. The ore is relatively good grade, but the loose brecciated nature of the rock and the lack of pitches made it difficult to follow and mine. The ore body plunges slightly toward the southwest and west. It is reported that an underlying ore body was discovered but never mined.

A small but high-grade zinc-lead ore body lies a few hundred feet south of the old mine. This ore body was opened in 1952 by the Homestead Mining Co. and operated by them until the latter part of 1953 as the Rasque mine.

Goke-Blockhouse mine (pl. 1, no. 180).—The easternmost mine of the main Blockhouse Range is the Goke-Blockhouse (fig. 91), in the SW¼SW¼ sec. 26, T. 3 N., R. 1 W. The deposit was discovered by drilling about 1920 and was operated by the Blockhouse Mining Co., from about 1921 to January 14, 1924. The shaft is 110 feet deep, into the Guttenberg member. The stopes are 7 to 17 feet high. Probably about 30,000 tons of zinc-lead ore was mined from this property.

The ore occurs in veins along the southward-dipping pitches and flats in the Ion and Guttenberg members.

Extensive drilling east of the east heading failed to show any immediate extension of the ore body in that direction. Probably lean ore or mineralized rock connects this ore body with the ore of the Cruson mine at the west.

Cruson mine (pl. 1, no. 181).—The Cruson mine (fig. 91) is in the SW¼SW¼ sec. 26, T. 3 N., R. 1 W. The zinc-lead ore body was discovered by drilling about 1908 by the Cruson Mining Co., and a shaft was sunk in 1909 to a depth of approximately 115 feet, into the Guttenberg member. The mine was operated until about January 1, 1912.

The ore body trends N. 45° E., and the parallel main pitch zone dips to the northwest. The trend of the ore body and strike of the pitches, plus the results of some drilling to the north, indicate that the ore body is in the central part of a local **S**-shaped turn of the Blockhouse Range. The sphalerite ore is mainly in the Ion and Guttenberg strata along well-developed pitches and flats.

Owing to the unsafe roof, a flat of ore from 4 to 18 inches thick possibly remains in the northwest wall of the mine along the base of the main pitch, and probably a narrow body of ore extends for a few hundred feet to the west, toward the east end of the Old Blockhouse mine.

Blockhouse mine (pl. 1, no. 182).—The Blockhouse mine (fig. 90) is in the S½SE¼ sec. 27, T. 3 N., R. 1 W. The zinc-lead ore body was discovered by drilling about 1914. Two shafts were sunk in 1916 into the Guttenberg member on the property by the Blockhouse Mining Co., and the mine was operated until 1921. The mine was one of the largest and richest mines of the Blockhouse Range.

The ore body has a general east trend and is more than half a mile long, and the stopes are from 7 to 16 feet high. However, along this general trend the ore body curves in a remarkable series of snakelike turns and loops, most of which trend north or northeast. The pitch zone dips most commonly southward as in other mines of the Blockhouse Range, but swings without a break around all the loops of the ore body.

The ore is in the Ion and Guttenberg members, and is in veins along the pitches and in well-developed flats.

Big Jack mine (pl. 1, no. 183).—The Big Jack mine (fig. 91) is in the SE¼SW¼ sec. 27, T. 3 N., R. 1 W. Before 1926 the zinc-lead ore body was discovered by drill holes put down by the Blockhouse Mining Co. The mine was operated from the latter part of 1941 until July 1942 by the Big Jack Mining Co. A shaft was sunk to a depth of 142 feet, to the Spechts Ferry member. The ore body has a general N. 35° W. trend and turns east at the southeast end, joining the west end of the Old Blockhouse mine. At the northwest end it turns west toward the Roseleip-Blockhouse mine (pl. 1, no. 184). The Big Jack mine has stopes 10 to 12 feet high. The ore body is controlled by a pitch zone dipping to the southwest and following the mine length, and the sphalerite ore occurs in veins along pitches and well-developed flats. Lead ore was produced with the zinc ore during the final month of operation.

Roseleip, Hi Spot, or New Blockhouse mine (pl. 1, no. 184).—This mine (fig. 91) is in the SW¼SW¼ sec. 27 and the SE¼SE¼ sec. 28, T. 3 N., R. 1 W. About 1925 the ore body was discovered by the Blockhouse Mining Co., and a shaft was sunk to a depth of 125 feet. The mine operated until February 16, 1929. The ore body has an easterly trend and was mined for a length of 2,750 feet, to a width of 15 to 60 feet, and to a height of 5 to 20 feet. At the shaft it widens locally to more than 100 feet.

The mine probably produced between 300,000 and 400,000 tons of zinc-lead ore that averaged about 10 percent zinc. The mine was a quite successful operation.

The ore body is controlled by a south-dipping pitch that strikes generally east. The ore occurs as veins along pitches and well-developed flats in the Ion and Guttenberg members.

Vinegar Hill Blockhouse mine (pl. 1, no. 185).—This mine (fig. 91) is in the S½SE¼ and SE¼SW¼ sec. 28, and the NW¼NE¼ sec. 33, T. 3 N., R. 1 W. Drilling by the Blockhouse Mining Co. discovered the zinc-lead deposit about 1923, and additional development was completed later by the Vinegar Hill Zinc Co. The mine was opened by the Vinegar Hill Zinc Co. in 1933 when a shaft was sunk to a depth of 170 feet. The mine was operated successfully until September 1936.

The mine produced about 127,000 tons of zinc ore.[75] About 700 gallons of water per minute was pumped to drain the mine.

The ore body has a general east trend but forms a southwest-pointing arcuate nose south of the shaft. The mine is controlled by a pitch zone that follows the trend of the ore body, has a general southerly dip, but swings around the previously described southwest-pointing nose without a break. The ore occurs in veins along the pitches and well-developed flats in the Ion and Guttenberg members of the Decorah formation.

Kistler and Stephens mine (pl. 1, no. 186).—The small Kistler and Stephens mine (fig. 92) is in the NW¼SW¼SW¼ sec. 28, T. 3 N., R. 1 W. It was operated profitably about 1917 or 1918 in a zinc-lead ore body discovered by the Blockhouse Mining Co.

The mine has a general east trend except at the east end, where a small prong extends northeast from the shaft. The ore occurs in the Ion and Guttenberg members of the Decorah formation.

[75] Data provided by the Vinegar Hill Zinc Co.

A narrow body of lean ore possibly extends between this mine and the Vinegar Hill Blockhouse mine to the east.

Seitz or New East End mine (pl. 1, no. 187).—This mine (fig. 92) is in the SE¼SE¼ sec. 29, T. 3 N., R. 1 W. Drilling by the Wisconsin Zinc Co. discovered the ore body about 1913, and it was mined successfully by that company from 1914 to November 21, 1916.

Probably between 50,000 and 100,000 tons of zinc ore was mined from this property.[76]

The ore body has a general easterly strike, but the west one-third consists of a remarkable series of snake-like turns and loops. The ore body approaches within 20 feet of the west property line, then turns north, and then east, forming a sharp arcuate nose. It then swings north, and at the heading trends N. 60° E. completing a contorted **S**-shape. The ore body is controlled by a pitch that dips generally southward, but follows all the twists and turns at the west end. The ore is found in veins along pitches and well-developed flats in all members of the Decorah formation.

A fairly good possibility exists of extending the mine northward from the "west" heading.

East End mine (pl. 1, no. 188).—The East End mine (fig. 92) is in the SW¼SE¼ sec. 29, T. 3 N., R. 1 W. Drilling by the East End Mining Co. discovered the zinc-lead ore body about 1911. A shaft was sunk to a depth of 110 feet, into the Guttenberg member, near the southwest corner of the property; and mining began in October 1918. The property was bought by the Wisconsin Zinc Co. and operated until May 6, 1914. Early in 1913 a second shaft was sunk, to a depth of 100 feet in the west-central part of the property.

The ore body has a general east trend but arcs toward the north, south, and west. The stopes are from 7 to 28 feet high.

In 1912 the mine produced high-grade jig concentrates averaging 48 percent zinc and the operators realized a large profit.[77] The ore body is worked out.

The sphalerite-galena ore is in veins along pitches and flats in the Ion and Guttenberg members. The controlling pitch zone, following the ore body, dips generally south. The flats are better developed than the pitches.

Klar-Piquette mine (pl. 1, no. 189).—The Klar-Piquette mine (fig. 92) is in the S½SW¼ sec. 29, T. 3 N., R. 1 W., and extends west nearly to a point below U. S. Highway 151 in sec. 30. This mine is one of the early Blockhouse mines, and its success stimulated the prospecting and development of the entire range. The Klar-Piquette Mining Co. was formed

[76] Estimate made by C. W. Stoops.

[77] Information provided by C. W. Stoops.

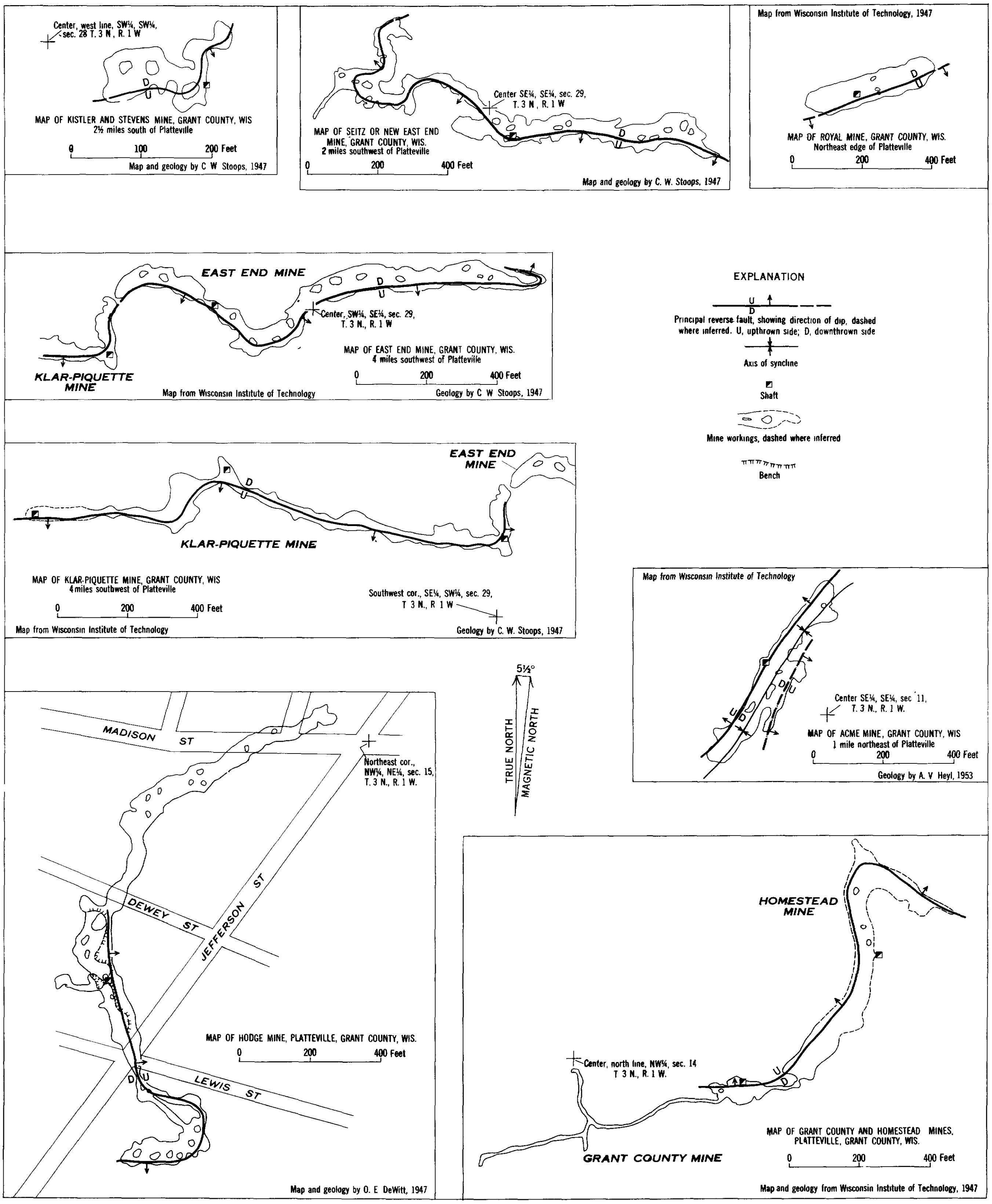


FIGURE 92.—Maps of the Kistler and Stephens, Seitz (or New East End), East End, Klar-Piquette, Hodge, Grant County, Homestead, Royal, and Acme mines.

about 1906, and the ore body was discovered by drilling in 1907. A shaft was put down to a depth of 110 feet, into the Guttenberg member, and mining began in 1908. In early 1909 the mine was idle, but it was reopened in the fall of 1909 and was operated quite successfully until 1915 by the Klar-Piquette Mining Co.

Probably about 350,000 tons of ore averaging 12 percent zinc was extracted from this mine.[78] The jig mill concentrate was high grade, approximately 50 percent zinc. About 400 gallons of water per minute was pumped to keep the mine drained.

The ore body has a general east trend but, like the other mines of this range, curves abruptly in places. The ore body is controlled by a pitch zone that trends east and dips south; the ore occurs in veins along well-developed flats and associated pitches. Numerous vertical joints that strike N. 50° E. cross the western part of the ore body. The ore is sphalerite and is very high grade.

St. Rose and New Rose mines (pl. 1, no. 190, and no. 164).—The St. Rose mine is in the S½SW¼ sec. 30, and in the N½NW¼NW¼ sec. 31, T. 3 N., R. 1 W. In 1902 the ore body was discovered in outcrops in the brook that passes through the old Toadville lead diggings. The St. Rose Mining Co. operated the mine until about 1912. The New Rose shaft, at the southwest end in the northeast corner of sec. 36, T. 3 N., R. 2 W., was reopened briefly in May 1944 by the M & H Mining Co., and was operated until January 1945 when the mine was flooded by breaking into the old St. Rose mine workings. The Little Grant Mining Co. reopened the New Rose mine in 1950 and mined a little ore from it.

The St. Rose mine is one of the few disseminated ore bodies that made a profit in the early twentieth century period of zinc mining. The total production of zinc ore of the St. Rose mine is probably about 100,000 tons. The New Rose mine produced a reported 1,550 tons of ore averaging 8 or 9 percent zinc in 1944 and 1945.

The St. Rose ore body trends generally N. 60° E., and is in nearly a straight line, but at the southwest end it turns towards the southwest and at the northeast end it turns to N. 75° E. The stopes are more than 2,100 feet long, about 80 feet wide, and 7 feet high. The high-grade sphalerite ore is mostly disseminated in the Guttenberg member and blue beds of the Decorah formation, and a little is in veins in flats in the northeast end. Very little galena and some iron sulfides are with the sphalerite.

Some ore probably remains in the mile separating the St. Rose and the west end of the Klar-Piquette mine to the east, and ore remained in at least one heading of the New Rose mine in 1950.

[78] Estimate made by C. W. Stoops.

Little Grant, Klondike, Brunton, or Weigle mine (pl. 1, no. 163).—The Klondike Mining Co. discovered this deposit about 1900 by means of an outcrop of disseminated sphalerite (Dugdale, 1900, p. 54). They opened the ore deposit by driving a drainage and haulage adit into the hill for 125 feet, where they struck the main ore body. A small jig mill was erected, and it and the mine were operated until 1904 or 1905.

Arensdorf and Murray reopened the mine in January 1942 and called it the Brunton or Weigle mine. They closed it in August 1942 because of insufficient operating funds, the low grade of the ore at the time, and because the ore contained too much shale for successful flotation.

The mine was reopened again by the Little Grant Mining Co. in June 1944 and it operated the mine fairly continuously and profitably until 1951 when it was sold to E. P. Scallon of Minneapolis. The Little Grant Mining Co. erected and operated a 50-ton gravity mill and located a northward extension of the ore body by drilling and a prospect shaft. In January 1954 the property was reported to be leased to Francis Piquette with an option by the American Zinc Co. It was no longer operating in 1957.

The access adit trends N. 40° E. and from it the workings consist of several parallel northeastward-trending ore bodies, connected by short drifts, that have an aggregate width of 400 feet, lengths of more than 400 feet, and heights that average 7 feet.

The ore bodies are controlled by several parallel faults that strike N. 18°–30° E. and dip southeastward. Disseminated crystals of reddish brown sphalerite and locally galena are the only ore minerals. They impregnate and replace the shalified beds of the Guttenberg and Ion members of the Decorah formation. The only gangue minerals are very small quantities of pyrite, marcasite, and calcite.

WHIG PATCH AND AREA WEST OF PLATTEVILLE

This long-abandoned part of the Platteville subdistrict contains many old lead mines and several zinc mines that were operated prior to 1915; it was abandoned because of the difficulty in handling the disseminated sphalerite deposits by the jig milling methods then common in the district. With modern flotation methods these deposits again have a potential commercial value. A little copper in the form of chalcopyrite locally accompanies the ore.

Tippecanoe mine (pl. 1, no. 112).—The Tippecanoe mine is in the NE¼NE¼NE¼ sec. 24, T. 3 N., R. 2 W. The ore body was discovered in 1899 by an outcrop of zinc ore (Dugdale, 1900, p. 52). The mine was opened through an adit extending southeast into the hill, and was operated by the Tippecanoe Mining Co., until about 1903. The operation was never much more than a prospect.

The ore body has a southeast trend, was probably worked for more than a hundred feet into the hill, and is 25 feet wide. The low-grade ore occurs as a band of disseminated sphalerite 2 feet thick, in partly shalified Guttenberg beds. The Spechts Ferry member, which is 4 inches thick, and the topmost beds of the Quimbys Mill are also exposed in the mine.

Some low-grade ore probably remains in the mine face.

Whig and Edgerton mines (*pl. 1, no. 160*).—The Whig mine is in the SE¼NE¼ sec. 12, T. 3 N., R. 2 W. The Edgerton is just to the south, in the NE¼SE¼ of the same section. Both mines began operations in 1904. The Edgerton mine was operated by the Trego Mining Co. The shaft is 150 feet deep, to the Spechts Ferry member, and the zinc ore body has an east trend.

The Whig shaft is 160 feet deep, probably to the Spechts Ferry member. The sphalerite ore is in the blue beds and the Guttenberg member of the Decorah formation and is disseminated.

The mineralized bodies were probably too low grade to be profitable.

Western Star mine (*pl. 1, no. 161*).—The Western Star mine is about a fourth of a mile east of the Edgerton mine, in the SE¼NE¼ sec. 12, T. 3 N., R. 2 W., and they are probably on the same ore-bearing trend. The Western Star shaft was sunk in 1904 to a depth of about 115 feet, to the Spechts Ferry member. A small quantity of disseminated sphalerite was found in the Guttenberg member, but it was not in paying quantities.

Capitola, or Phillips and Rice mine (*pl. 1, no. 179*).—This mine is in the NW¼SE¼ sec. 18, T. 3 N., R. 1 W. The ore body was discovered in 1900 in outcrops exposed in a small tributary of the Little Platte River, and an adit was driven 40 feet west into the hill (Dugdale, 1900, p. 50). By 1902 the adit and stopes had been extended to a length of 80 feet and, before it was closed around 1906, it is reported to have been about a fourth of a mile long.

The ore body is not particularly high-grade, and much of the zinc-bearing material was lost in hand-sorting and thrown on the mine dump. The tonnage mined was probably not very large. It is reported that some ore remains in the mine, as the floor of the stopes is said to have risen above the ore band at the west end of the mine.

The ore is disseminated sphalerite in a band about 2 feet thick in the lower part of the Guttenberg member and in the Spechts Ferry member. The deposit is structurally unusual, as it follows along the north edge of the Capitola reverse fault that strikes N. 80° E., dips south, and shows about 30 feet of vertical displacement. The ore body is in the downthrown footwall side. The limestone beds have been highly altered by shalification and dolomitization and near the mouth of the adit a small vertical sandstone dike fills a fracture in the Platteville formation.

Graham and Stephens mine (*pl. 1, no. 178*).—This formerly important and profitable mine is on the east side of the Little Platte River along the center line of the E½ sec. 18, and extends into the southwest corner of the NW¼ sec. 17, T. 3 N., R. 1 W. The mine was opened in 1897 by an adit driven into the hill in a N. 80° E. direction, and was operated until September 1910. The main shaft, about 100 feet deep, is in the southwest corner of the SW¼NW¼ sec. 17. The zinc ore body has been mined for at least 1,100 feet; it has a width of 50 feet, and probably a height of about 14 feet.

Descriptions of this mine may be found in the reports of Grant (1903, p. 74) and Dugdale (1900, p. 50). The total production from this mine is not known but it was probably quite large. No pumping was necessary.

The ore is disseminated sphalerite in the blue beds of the Decorah formation and in the Guttenberg member; it is of a good grade, is lean in iron sulfides, and contains some chalcopyrite. Much dolomitization and shalification has altered the Guttenberg member.

It is reported that a face of good ore remains at the east end of the mine.

M. and H. mine.—The M. and H. mine is in the NW¼ sec. 16, T. 3 N., R. 1 W. It was operated from about 1913 to 1917. The shaft is about 100 feet deep, to the Spechts Ferry member. The ore body probably has a N. 80° E. trend. The mine was successful in the later years of its operation when the market prices during the first World War were high. No production figures are available. A brief attempt to reopen it was made during the second World War.

The ore is sphalerite disseminated as crystals in the blue beds of the Decorah formation and in the Guttenberg member, and is relatively low grade.

West Hill mine (*pl. 1, no. 177*).—About 750 feet northeast of the M. and H. is the West Hill mine, which is S-shaped in pattern.

The shipped ore averaged between 9 and 10 percent zinc,[79] but was hand-sorted concentrate.

Southeast from the shaft the pitch zone, the zinc ore body, and stopes curve west, and form an arcuate nose. About 100 feet northwest of the shaft the ore body turns

[79] Data provided by C. W. Stoops.

toward the north, and then northeast, and at the northeast end it trends N. 70° E. A parallel west-dipping pitch zone is probably about 140 feet west of the shaft, but this zone was not worked to any extent, as the ore was too lean to mine. The ore is veins of sphalerite along well-developed pitches and flats in all members of the Decorah formation.

MINES EAST AND NORTH OF PLATTEVILLE

Several mines that have been very successful operations are in this part of the subdistrict. The Empire and Enterprise were famous for their large profits and were among the first district mines in which large-scale mining and milling methods were successful. Their success gave impetus to the mining boom that prevailed in the district during 1905–10.

Most of the ore bodies in this part of the subdistrict are vein deposits in well-developed pitches and associated flats. Barite is a common constituent of ores, and chalcopyrite is a minor one.

Hodge mine (pl. 1, no. 176).—The Hodge mine (fig. 92) is in the NW¼NE¼ sec. 15, T. 3 N., R. 1 W., in the northeast part of Platteville, Wis. The zinc ore body was discovered by drilling prior to 1910, and mining was attempted. In 1910 Howe Brothers reopened the mine and started producing. In 1915 the property was taken over and reopened by the Vinegar Hill Mining Co.; operations continued until the summer of 1917.

The mine has a general north trend, and its stopes are 30 to 100 feet wide and 35 to 40 feet high. The shaft, now filled, is about 145 feet deep, to the Spechts Ferry member.

The mine produced 40,000 tons of 8 to 9 percent zinc ore in 1915 and 1916,[80] and the total production probably exceeded 100,000 tons. Near the shaft the ore body is controlled by an east-dipping, north-striking pitch zone. The same zone may control the entire ore body.

Empire and Enterprise mines (pl. 1, nos. 173 and 174).—These two formerly very important mines (fig. 93) are in the same zinc-lead ore body in the east part of Platteville, Wis., in the S½SE¼NE¼ sec. 15, and the NW¼ sec. 14, T. 3 N., R. 1 W. The Enterprise is southwest of the Empire, and is the first part of thee ore body discovered. It was discovered by drilling in April 1899 by the Enterprise Mining Co. The Empire mine, owned by the Empire Mining Co., began operations in July 1902. The Enterprise operated until about 1907 and the Empire mine until about 1914. In the later years the Wisconsin Zinc Co. operated the Empire mine.

Each mine has three shafts between 125 feet and 150 feet deep. The mines are connected by continuous stopes that have a general N. 65° E. trend. Their total length is 4,800 feet, and the ore body is 80 to 100 feet wide and 20 to 30 feet high. The mines are well described by Grant (1903, p. 67–79) and Bain (1906, p. 93–97), who visited them while in operation.

The actual production of ore from these mines is not known but it is probably about 900,000 tons of mostly high-grade zinc-lead ore. The jig concentrates of the Empire mine averaged 30 percent zinc in 1912.[81] Both mines were very profitable and paid very large dividends to the stockholders.

The ore body lies on the southeast flank of the first-order Platteville syncline, which here has a N. 65° E. trend. It is also controlled by a pitch zone of northeastward strike that dips toward the southeast.

The ore is in veins and is high grade for the district, though containing considerable iron sulfide. Calcite, barite, and chalcopyrite are accessory minerals in the ore.

West Empire mine (pl. 1, no. 175).—The West Empire is southeast of the Hodge mine and northwest of the Empire mine, in the northeast corner of the SW¼NE¼ sec. 15, T. 3 N., R. 1 W. The property was opened and operated by the West Empire Mining Co., in 1906; it was operated again during 1908, but was closed before 1909. The mine apparently was not very successful.

The ore body has a N. 12° W. trend, and was mined for a 200-foot length, and to a 30 to 50 foot width for zinc sulfide. The ore body is reported to have contained a sphalerite vein 8 inches wide.

Hibernia mine (pl. 1, no. 169).—This small mine is in the northeast corner of the SE¼SE¼ sec. 10, T. 3 N., R. 1 W., at the north edge of Platteville, Wis. The company was formed about 1903, the shaft reached a depth of 160 feet, and the property was closed about 1906. The zinc-iron sulfide ore body was opened by a drift or stope that was mined 300 feet east of the shaft and a second one that extended 160 feet north from the shaft. Both of these workings are reported to be in ore.

The shaft penetrated into the Guttenberg member and the drifts are presumably in the Guttenberg and blue beds of the Decorah formation. The ore is notably rich in iron sulfides and probably the mine was closed for this reason.

Trego mine and Great Northern mine (pl. 1, no. 165).—The Trego mine (pl. 11) is in the E½SE¼ NW¼ sec. 10, and the S½NW¼ sec. 11, T. 3 N., R. 1 W. The old Great Northern mine is near the east end of the south limb of the Trego zinc-lead ore body and is now part of the Trego mine. The Trego ore body was dis-

[80] Data provided by the Vinegar Hill Zinc Co.

[81] Data provided by C. W. Stoops.

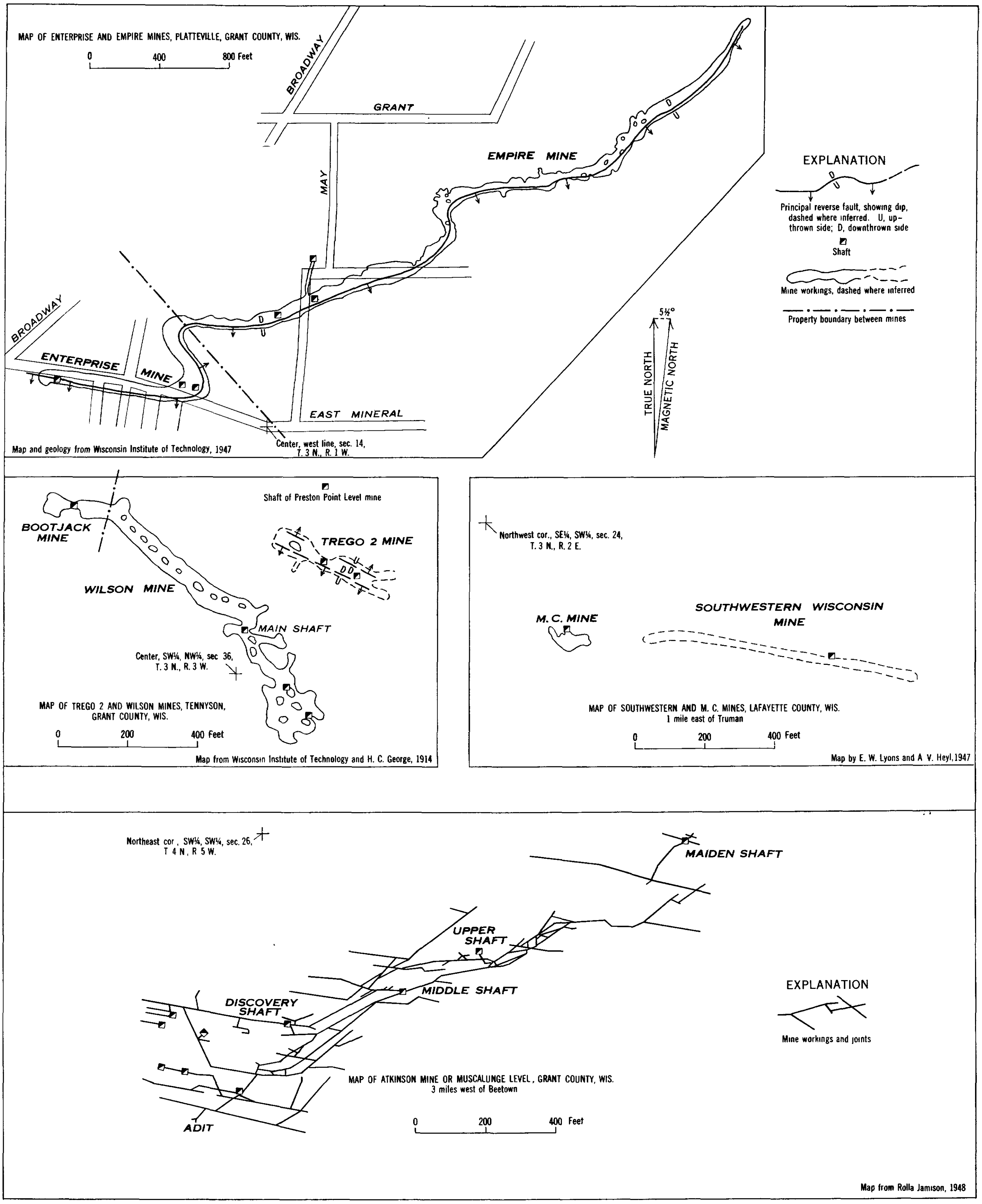


FIGURE 93.—Maps of Enterprise, Empire, Southwestern Wisconsin, M. C., Trego No. 2, Wilson, and Atkinson mines.

covered by drilling by the Platte Zinc Co. about 1905. A shaft was sunk to a depth of 145 feet, and the upper parts of the ore body were mined in the west arcuate end. The mine was closed about 1908. The Big Four Mining Co. reopened the mine in 1910, deepened the shaft to 150 feet, and did some additional mining. The Great Northern part of the ore body was discovered by drilling about 1905. A shaft was sunk in 1906 to a depth of 160 feet, into the Guttenberg member. Stoping was done for about 100 feet east and west from a short drift driven south from the shaft, but the mine was closed owing to the leanness and excessive marcasite in the ore. The land near both mines was drilled by the Wisconsin Zinc Co. in 1918 and much additional ore was discovered.

The Trego mine was reopened in March 1943 by the Piquette Mining Co., and operated successfully until September 1945 when it was closed again owing to the leanness of the ore at the headings.

The grade of the hand-cobbed zinc ore mined by the Piquette Mining Co. ranged between 3 and 7 percent zinc and contained about 10 to 15 percent iron sulfide, which was recovered by the Vinegar Hill Zinc Co. for sulfuric acid. The total production of ore of this mine by all companies probably exceeds 100,000 tons.

The geology of the Trego mine has been described (p. 115–119).

The ore contains sphalerite, galena, abundant pyrite and marcasite, large calcite crystals, a little barite, chalcopyrite, and locally a trace of greenockite. All the rocks are completely dolomitized by fine-grained pale-pink dolomite, which also is in veins (fig. 67), accompanied by notably little solution thinning of the strata.

The headings at the east ends of both the north and south limbs of the ore body, when closed in 1945, showed lean ore, rich in marcasite, that contains 2 to 3 percent zinc as sphalerite. Such ore extends for several hundred feet beyond the headings. Some ore may also remain at the west arcuate nose, and beneath the present floor of the north limb near the west nose. The other parts of the ore body have been worked out.

Columbia mine (pl. 1, no. 166).—The Columbia mine is in the center of the SW¼NE¼ sec. 11, T. 3 N., R. 1 W. The mine was opened and operated by the Columbia Mining Co., about 1908, but, after stoping and drifting for 100 feet south from the 150-foot shaft, they closed the mine, probably because of the leanness of the zinc ore. The ore body, which supposedly trends east, is in the Decorah formation.

Grant County (Lucky Four) and Homestead mines (pl. 1, nos. 172 and 167).—These two mines (fig. 92) are in the same zinc-lead ore body. The Grant County mine is in the northwest corner of the NE¼NW¼ sec. 14, and the Homestead is to the northeast, in the S½SE¼SW¼ sec. 11, T. 3 N., R. 1 W. The mining in this ore body was done in the Grant County mine by the Lucky Four Mining Co., which sank a shaft to a depth of 96 feet in July 1903. By 1906 the Grant County Mining Co. had taken over the mine, and the company operated it until about 1913. The Homestead part of the ore body was discovered by drilling about 1907, and the mine was operated by the Homestead Mining Co. from 1908 to 1913. During the period 1942–1953 several attempts to reopen the Homestead mine were started, but never advanced beyond the initial stages.

The ore body in which the two mines operated has a length of nearly 2,000 feet, each mine being about 1,000 feet long. The ore was mined from narrow drifts at the west part of the Grant County mine but in the east part the stopes are 60 feet wide. The Homestead stopes have an average width of 80 feet. The ore body has a general northeast trend, but turns sharply to form an arc at the northeast end.

The ore body lies on the northwest flank of the N. 60° E.-trending syncline that has the Royal, Empire, and Enterprise ore bodies (p. 248) along its southeast flank, and is controlled by a northwest-dipping pitch. The ore is found in all the beds from the Prosser member downward into the Guttenberg member; at the east end of the Homestead mine the ore is pretty well limited to these two units. The zinc-lead ore is in veins and is rich in iron sulfide.

Both mines were probably financially successful and the Homestead was very profitable. The tonnage of ore mined is not known, but probably exceeded 200,000 tons. In 1912 a roasted and magnetically separated jig concentrate that averaged 50 percent zinc [82] was shipped from the Homestead.

Considerable ore might remain beneath the floor of the Homestead mine, for it is reported that only the upper part of the ore body was mined to any extent. Also, the east heading of the Homestead mine is in ore.

Royal mine (pl. 1, no. 171).—Royal mine (fig. 92) is just northeast of the northeast end of the Empire mine, in the northwest corner of the NE¼ sec. 14, T. 3 N., R. 1 W. Drilling in 1906 by the Royal Mining Co. discovered the zinc ore body; that company operated the mine during 1907 and then closed it. The ore body has a N. 70° E. trend, lies on the southeast flank of the N. 60° E. trending Platteville syncline and is controlled by a parallel, south-dipping pitch zone. The low-grade ore occurs as veins that fill the flats and

[82] Data provided by C. W. Stoops.

pitches in the Ion and Guttenberg members of the Decorah formation.

Acme mine (pl. 1, no. 168).—The Acme mine (fig. 92) is in the SE¼SE¼ sec. 11, T. 3 N., R. 1 W. The ore body was discovered by drilling about 1906 by the Acme Mining Co., and the mine was operated during 1907 and 1908. In 1952 the mine was reopened and operated by the Homestead Mining Co., but it was closed again in 1953. This company erected a flotation mill on the property and processed ores from the Acme and also the Royal mine. The mine probably produced more than 100,000 tons of ore during its 2 periods of operation.

The ore body is probably an extension of the Homestead ore body (p. 250) and lies along the axis of a syncline that trends N. 30° E. The zinc ore is in veins along the pitches and flats and is rich in iron sulfide in the Ion and Guttenberg members of the Decorah formation.

Drill holes that contain some ore extend about 300 feet to the southwest and west of the ore body toward the Homestead mine.[83]

Mitchell Hollow mines (pl. 1, no. 170).—The two Mitchell Hollow mines are about a quarter of a mile apart, in the N½SE¼SW¼ and the N½SW¼SE¼ sec. 12, T. 3 N., R. 1 W. The small zinc deposits were discovered by drilling of the Wisconsin Zinc Co. in August 1908, and the mines were opened by that company in 1909. Two shafts were put down into the Guttenberg member, the west one about 140 feet deep, and the east one about 155 feet deep. The mines were operated in 1909 and 1910 and were then closed. The ore was processed in a gravity mill, which later was used to concentrate lead-zinc ores from Colorado.

The west mine was worked for 300 feet at a width of 20 to 60 feet. This part of the ore body has a N. 80° E. trend and is controlled by a pitch zone that dips to the south. The mine is at the east end of the Platteville syncline that also contains the Empire, Homestead, and other mines at the east edge of Platteville, Wis.

The east mine is more irregular, but its longest dimension is in the east direction, along which it was mined for 100 feet. The stopes are mainly northeast, and northeast from the shaft.

Beacon Light mine (pl. 1, no. 193).—This small mine is in the SW¼NW¼ sec. 18, T. 3 N., R. 1 E. A company was formed in 1906, and in that year the ore body was discovered by drilling. The shaft was sunk in 1908, but probably was never completed to the depth originally planned. Apparently a small amount of stoping was done but the mine was closed in 1910 owing to the abundance of water. Ore of good grade occurs in a solution breccia in the Prosser member of the Galena dolomite, but it contains considerable pyrite and marcasite. A small ore body might possibly be developed here by more prospecting.

Kingeter mine (pl. 1, no. 194).—The Kingeter mine is in the NW¼NE¼NE¼ sec. 19, T. 3 N., R. 1 E. The Kingeter Mining Co. was formed in 1906, and the ore body was found by drilling about that year. The ore is disseminated sphalerite quite rich in galena, and occurs at a depth of 95 to 100 feet. The property was closed when the shaft was about 15 feet above the ore zone.

CALAMINE-TRUMAN-DARLINGTON SUBDISTRICT

The Calamine-Truman-Darlington subdistrict (pl. 1) is roughly triangular in shape and lies about midway between the east part of the Hazel Green-Shullsburg subdistrict and the Mineral Point subdistrict, and the known ore deposits are more widely spaced than in many other parts of the district. The lead deposits are widely scattered and, except for a few, were never of great commercial importance. From early times the lead mines were noted for the abundance of zinc carbonate, and it was from this fact that the town of Calamine derived its name; "calamine" is the British equivalent of the American term smithsonite.

Smithsonite was recovered from these deposits from 1860 to about 1900. Small tonnages of zinc sulfide were mined in the part of the area east of Truman from 1900 to 1915.

All the workable lead and zinc deposits occur in the Platteville, Decorah, and Galena formations, and most of the known sphalerite ores are restricted to the Quimbys Mill and Guttenberg members.

The stratigraphic section differs from that in the previously described areas mainly in the Quimbys Mill, Spechts Ferry, and Guttenberg Mill members. The Guttenberg member is only 5 to 7 feet thick and the Spechts Ferry member is only a few inches thick; on the other hand, the Quimbys Mill member has thickened to 12 or 14 feet. The uppermost members of the Galena dolomite are not present throughout most of the area, owing to erosion. In the eastern part of the subdistrict the normally limestone members of the Platteville and Decorah formations are dolomite.

The subdistrict is at the east end of the Platteville syncline (pl. 8), which depresses the rocks to such an extent that the St. Peter sandstone, exposed to the north and south, disappears beneath the floor of the Pecatonica River, at Calamine, Wis. Most of the known ore deposits lie within this general synclinal area. The location and pattern of the smaller folds are not known inasmuch as the area has not been mapped in

[83] Information furnished by Wisconsin Institute of Technology, 1953.

detail geologically.[84] The abundance of zinc and the several known ore bodies give this subdistrict some promise as a potential zinc producer. Drilling in 1953 by the U. S. Geological Survey located a large area of promise west southwest of Darlington.

Southwestern Wisconsin mine (pl. 1, no. 196). This mine (fig. 93) is at the east edge of the SW¼ sec. 24, T. 3 N., R. 2 E., just east of the M. C. mine. The ore body was found about 1906 by shaft sinking in old lead diggings, and the mine was operated by the Lancaster Mining Co. from 1906 to at least 1909.

The shaft is 80 feet deep, to the base of the Quimbys Mill member. The ore body has a N. 80° W. trend that can be traced by shallow lead diggings for at least 1½ miles. The workings average 6 feet high.

Possibly 4,000 or 5,000 tons of ore worth about $18,000 was mined. The hand jig concentrate assayed 53 percent zinc.[85] No water had to be pumped.

Sphalerite occurs both in veins and replacements in the Quimbys Mill member. The veins average 1 inch thick but in places are 2 or 3 inches thick. The disseminated sphalerite is found about 4 feet below the vein ore. Barite is abundant in the ore, and iron sulfide content is low.

M. C. mine (pl. 1, no. 195).—The M. C. mine (fig. 93), several hundred feet west of the Southwestern Wisconsin mine, is in the center of the SW¼ sec. 24, T. 3 N., R. 2 E. The ore body was discovered about 1912 by drilling, and the mine was operated during 1913 by the M. C. Mining Co. The shaft is 80 feet deep, to the base of the Quimbys Mill member. The stopes are 50 feet wide, about 20 feet high, and extend for at least 120 feet in a general N. 80° W. direction.

The mined ore averaged 8 to 10 percent zinc[86] and yielded a jig concentrate said to average 40 percent zinc, 6 percent iron, and 11 percent barium. In early 1913 a shipment was made of 120 tons of zinc concentrate and 8 tons of lead concentrate. The abundance of barite and the wide separation of the ore zones by barren rock were undoubtedly factors leading to abandonment of the property. The ore occurs in two zones at the top and at the base of the Quimbys Mill member, separated by 10 or 12 feet of barren dolomitized rock. The lower zone consists of 2-inch veins of zinc sulfide in veins associated with calcite, galena, and abundant barite. The upper zone is locally disseminated, and the ore tends to be somewhat irregularly distributed.

Ore probably remains in the 150 feet between the east face of this mine and the west face of the Southwestern Wisconsin mine. At the suggestion of the U. S. Geological Survey, the U. S. Bureau of Mines (Apell, 1949) drilled to the west of the M. C. mine and found that the ore body extended for several hundred feet in this direction as a flat at the base of the Quimbys Mill member. Thin pitches were noted in the Decorah formation above in diamond drill cores.

[84] Detailed geologic mapping of the area was in progress in 1957.
[85] Data provided by C. W. Stoops.
[86] This information and the data that follows provided by C. W. Stoops, geologist.

POTOSI SUBDISTRICT

The Potosi subdistrict, west of the Platteville subdistrict (pl. 1), was formerly a very important lead producing area; in the latter part of the nineteenth century it produced more lead than any other center of mineral deposition except the Hazel Green-Shullsburg subdistrict. Between 1862 and 1876 it produced more than 21,300 tons of 80 percent lead concentrates (Strong, 1877, p. 643–652).

From 1900 to 1918 zinc was mined at intervals from shallow gash-vein ore bodies in the Galena dolomite, and a few unsuccessful attempts to mine ore in deeper strata were made. Zinc mines were operated throughout the subdistrict (pl. 6), but most successful mines are just east of Tennyson, Wis. In 1945, drilling proposed by the U. S. Geological Survey and conducted by the U. S. Bureau of Mines at Tennyson proved the presence of ore bodies of mineable grade in the lower part of the Galena dolomite and the Decorah and Platteville formations (Apell, 1947). In 1957, the successful mining of these ores was in progress by the Piquette Mining Co.

The stratigraphy conforms to that of the central part of the district, except the Spechts Ferry is much thicker, being about 6 feet thick, and the Quimbys Mill has thinned to 1 or 2 feet. The full thickness of the St. Peter sandstone and the upper part of the Prairie du Chien group are exposed along the Platte River Valley, to the east, and along its tributaries, near their mouths. Erosion has removed the upper beds of the Galena dolomite except locally.

The area is more deformed than some other parts of the district. In the southern part of the subdistrict the beds are depressed by the Platteville syncline, which crosses the area southwesterly, passing through Tennyson and Potosi. North of British Hollow a large eastward-trending syncline passes through the area (pl. 6). The area is bounded both on the south and on the north by northeastward-trending anticlines. These folds have amplitudes of 20 to 60 feet. Locally bedding-plane, reverse, and normal faults are present. Most of these faults have only a few feet of displacement. A major bedding-plane fault and an anomalous structural relationship east of Tennyson have been previously described (p. 120–121).

In the Decorah and underlying Platteville formations the zinc ore is commonly disseminated, or in veins with disseminated replacement boundaries. This ore is probably controlled by reverse and bedding-plane faults. The known deposits in the Decorah and Platteville beneath have east and northeast trends. The zinc deposits in the Prosser cherty and overlying Stewartville massive members above are in breccia zones that trend parallel to the surface lead deposits, about N. 50°–80° W.

The lead deposits are in gash-veins and openings along mineralized joints and are notable for their length and continuity (pl. 6).

Tiffany mine (pl. 1, no. 205).—The Tiffany mine (pl. 6) is in the SE¼NW¼ sec. 36, T. 3 N., R. 3 W. The ore body was discovered by drilling about 1915 by the Tiffany Mining Co. The mine was operated in 1916 and 1917, and it was closed because the ore was too lean to be profitable. The shaft is about 75 feet deep, into the lower *Receptaculites* beds of the Prosser cherty member. The ore body has a N. 80° W. trend and has been stoped to a height of about 10 feet.

The tonnage mined is not known but probably was between 10,000 and 20,000 tons of ore that averaged about 2 percent zinc. The ore yielded a 30 to 35 percent jig concentrated.[87]

The ore is in breccia and veins. The vein sphalerite is rich in iron and is nearly black. The pyrite and marcasite content is quite low. Ore of this type probably remains in the east and west mine headings.

U. S. Bureau of Mines drilling in 1945 (Apell, 1947), mainly west of the west heading where the structure and surface indications were favorable, showed the presence of low-grade ore ahead of the west face, but failed to show any ore at greater depth.

Pleumer Level.—An adit, called the Pleumer Level (pl. 6, no. 44), was driven west into the hill from the west side of a small northeast-flowing valley in the NW¼SE¼NE¼ sec. 36, T. 3 N., R. 3 W. about 1906. The small mine dump indicates that the Pleumer Level was little more than a prospect, and that little ore was produced.

The adit was driven in the blue beds of the Ion member 35 feet south of the north-dipping reverse fault that strikes N. 85° W. and has a 3-foot displacement. A major bedding-plane fault is exposed in the Spechts Ferry member about 100 feet north of the adit.

A small stockpile of sphalerite ore of good grade was on the mine dump in 1950. The sphalerite is in large brown crystals that replace blue beds of the Ion member. A small quantity of pyrite is the only gangue mineral.

[87] Data provided by C. W. Stoops.

This prospect is geologically favorable, and other ore bodies might be found in the hills immediately to the east and west of the adit along the strike of the reverse fault. Waters from springs to the northwest that flow from the hill west of the mine showed unusually large quantities of zinc in solution when tested by field geochemical methods.[88]

Piquette mine.—The first large zinc-lead mine in the Decorah formation and lower part of the Galena dolomite was opened in late 1954 by the Piquette Mining Co. and the American Zinc Co. in the SW¼NE¼ sec. 36, T. 2 N., R. 3 W. Access is by a truck adit extending west from the mouth of the Pleumer adit, now destroyed, into the westward-trending ore body which extends westward from the Pleumer adit site to east and north of the Tiffany mine. A substantial tonnage of high-grade mining ore was developed and a 300-ton flotation mill was nearly completed in 1954 (Skillings, 1955, p. 8). The property was still in successful operation in June 1957 and had notably low mining costs.

The ore body trends about N. 80° W. and is controlled by a series of vein-filled small normal and reverse faults that strike N. 80° W. The ore is in veins and disseminated and is rich in galena and sphalerite.

Tennyson mine.—A small mine, called the Tennyson (pl. 6, no. 35) is located in the northwest corner of the SW¼SE¼ sec. 36, T. 1 N., R. 1 E. The mine, operated sometime between 1900 and 1910, has a shaft about 200 feet deep into the Guttenberg member. The mine is at the southeast end of a line of old lead diggings that trend N. 60° W.

The ore is deposited in the Decorah formation, and is pale-brown sphalerite, accompanied by marcasite and a little chalcopyrite.

Preston Point Level (pl. 1, no. 204).—The Preston Point Level (pl. 6, mine 42) is along the eastward-trending center line of the NW¼ sec. 36, T. 3 N., R. 3 W. An adit, for the dual purpose of recovering galena and for dewatering the deeper parts of the lead-bearing Kendall, Preston Point, and Cave Lead ranges, was driven into the hill from the north side of Tennyson Branch by the Dutch Hollow Level Co. from 1870 until after 1876 (Strong, 1877). The adit and stopes are about 2,200 feet long. The first half of the workings are barren of ore, but beyond the south turn lead ore was struck. A little disseminated zinc ore accompanies the galena. In 1872 this level produced 30 tons of lead concentrate (Strong, 1877) and the total production was probably much more. However, it is doubtful that

[88] Vance C. Kennedy, U. S. Geological Survey, written communication to Lyons, 1949. These geologic indications led to the discovery of a new zinc-lead ore body now (1957) being operated on a large scale by the Piquette Mining Co. (See Piquette mine.)

the operation ever made a profit. The ore is in the Prosser cherty member of the Galena dolomite in a coarse, irregular breccia near the axis of a N. 70° W. syncline (Chamberlain, 1882, p. 433, 447, 467–468).

Trego No. 2 mine (*pl. 1, no. 203*).—The Trego No. 2 mine (fig. 93) is in the center of the NE¼SW¼NW¼ sec. 36, T. 3 N., R. 3 W. The zinc-lead ore body was discovered by drilling, probably in 1901. The mine was opened in 1902 by the Trego Mining Co., and operations continued until about 1904. The mine was reopened probably in 1917 by the Wilson Mining Co. The two shafts are 80 to 90 feet deep.

The production from the mine is not known but estimating from the size of the workings it was probably between 20,000 and 30,000 tons of zinc and lead ore. The flotation mill of the Piquette Mining Co., in operation in 1957 on ore from adjacent properties is located on the site of this mine.

The ore body has a N. 63° W. trend and is controlled apparently by a N. 60° W.-trending syncline; the ore body, a middle run deposit, occurs in a highly brecciated zone in the Prosser cherty member between outward-dipping pitches. The ore is mainly sphalerite accompanied by much galena, and contains very little iron sulfide.

Low-grade ore remains in the two headings; ore in the northwest one is estimated to average 3 percent zinc and that in the southeast one 2 percent zinc.

Wilson and Bootjack mines (*pl. 1, no. 202*).—The Wilson mine (fig. 93) is in the SW¼NW¼ sec. 36, T. 3 N., R. 3 W. The ore body was discovered by drilling, probably in 1914, and mining commenced by the Wilson Mining Co. in 1915 and continued at least until 1917. The mine was reopened through a new shaft at the northwest end by the Bootjack Mining Co. and called the Bootjack mine, in 1940, and then abandoned again in that year. The Bootjack shaft, in the northwest part of the ore body, is about 105 feet deep and the main Wilson shaft is 80 feet deep.

Production from the Wilson mine is not known but probably 50,000 tons of zinc-lead ore averaging about 4 percent zinc was mined. This yielded a 50 percent zinc jig concentrate.[89] The Bootjack (Gill) mine produced a reported 28 percent zinc jig concentrate in 1940, averaging 5.4 percent iron and 1.9 percent lead.

The ore body is apparently controlled by a northwestward-trending fracture system, and the ore cements blocks of a coarse breccia in the middle beds of the Prosser cherty member. The deposit is classified as a middle run deposit.

The ore is mainly sphalerite in coarse crystals and veins that also contain marcasite and galena.

[89] Data provided by C. W. Stoops.

Some low-grade ore estimated to average 2 percent zinc, remains in the southeast heading of the Wilson mine, and the northwest heading is reported to have good ore in the face. However, a crossline of drill holes by the U. S. Bureau of Mines about 350 feet to the west of the northwest face failed to show ore of mineable grade (Apell, 1947).

Piquette prospect.—A company headed by Francis C. Piquette prepared to open an ore body underlying the village of Tennyson (pl. 6) in 1957. This ore body, which was discovered by Piquette in 1945, was explored in drill holes by the U. S. Bureau of Mines (Apell, 1947) in cooperation with the U. S. Geological Survey. It is the first large zinc ore body found in the Decorah formation in the Potosi subdistrict. The company is planning to open the deposit by an incline driven westward from near the Wilson mine, which they were also planning to reopen.

The ore body trends eastward and partly underlies the main street of Tennyson. Near the west end it turns toward the north. The ore is mostly in the Decorah formation, but locally extends into the Galena dolomite above and Platteville formation below. The tabular ore body is 40 to 120 feet wide, and where drilled by the Federal Government, it is 6 to 15 feet thick, although in one place it was 40 feet thick. The ore is sphalerite and galena, lean in marcasite and pyrite, in replacements and thin fissure veins mostly along bedding planes. Much of it is high grade.

Cardiff No. 2 mine (*pl. 1, no. 201*).—The Cardiff No. 2 mine (pl. 6, mine no. 19) in the southeast corner of the NE¼SE¼ sec. 34, T. 3 N., R. 3 W., was operated in 1904–1905 by the Cardiff Mining Co. The shaft was sunk to a depth of 212 feet into the Guttenberg member.

It is reported that zinc ore was found in the gray beds of the Decorah formation when the ore body was drilled, but this "ore" may have been due to self-salting of the drill holes because the material on the dump fails to show any sulfide minerals from these beds. However, some zinc ore fairly rich in iron sulfide was struck in the drill holes and in the shaft at a depth of 95 feet in the Prosser. This ore appears to be of good grade, but the size of the ore body is not known. The mine was closed apparently because of too little ore.

Krog and Webster mine (*pl. 1, no. 200*).—This small lead-zinc mine (pl. 6, no. 7) is in the E½NE¼SE¼ sec. 26, T. 3 N., R. 3 W. It was prospected by drilling by the Krog and Webster Mining Co. about 1902. The shaft was 90 feet deep in 1903, and probably was later deepened to at least 140 feet, into the Guttenberg member. The mine was closed about 1919 after some galena was taken out, because the ore body was not considered to be of mineable grade.

The ore body is on the south flank of a local eastward-trending syncline and the beds in the mine dip 3° to 5° N. The ore body is controlled by an eastward-striking, south-dipping pitch zone.

The ore is mainly galena, in thin flats, in veins, and pitches in the Prosser strata of the Galena dolomite. Disseminated sphalerite occurs sparingly at a depth of 105 feet, in the gray beds of the Decorah formation, associated with large crystals of galena; sphalerite is reported to exist also in veins along the pitches.

The property is structurally favorable, and the presence of some zinc ore in the gray beds of the Decorah formation is of interest. Additional prospecting east and west of the mine might lead to the discovery of mineable ore.

Cardiff No. 1 mine (pl. 1, no. 199).—The Cardiff No. 1 mine (pl. 6, no. 6), at the center of the N½ sec. 25, T. 3 N., R. 3 W., was operated by the Cardiff Mining Co. about 1903.

The ore body has a N. 35° W. trend and is located within a well-defined eastward-trending syncline. It is marked by numerous shafts along a length of 500 feet. The shafts are probably about 60 feet deep, into the gray beds of the Decorah formation.

The minerals are mainly marcasite and a little disseminated sphalerite in a solution breccia. Some smithsonite was found in the lower Galena beds. Mineable ore apparently was not discovered.

Horseshoe mine (pl. 1, no. 198).—The Horseshoe zinc mine (pl. 6, no. 2), along the line between the SW¼ sec. 24, and the NW¼ sec. 25, T. 3 N., R. 3 W., was operated by the Horseshoe Mining Co., at intervals between 1906 and 1909. The shaft is 140 feet deep, into the blue beds of the Decorah formation. The workings consist of drifts extending to the southwest and southeast from the shaft. The ore body is 20 feet high and 20 feet wide.

Production from this mine is not known, but it was small. In 1911 about 3,000 tons of ore remained in a pile at the shaft (part of which was still there in 1953). Fines from this pile assayed 12.4 percent zinc and 28 percent iron, and the coarse material assayed 24.3 percent zinc and 25 percent iron.[90]

The sphalerite ore is in round, concentrically banded balls embedded in marcasite against the wall rock of Prosser cherty member of the Galena dolomite. The deeper beds are barren except for calcite. The sphalerite is almost black and its balled habit is unique in the district.

Little Horseshoe mine.—The Little Horseshoe shaft is one-fourth mile west of the Horseshoe mine in the Craig Range (pl. 6, mine 5). The shaft is about 225 feet deep to the Spechts Ferry member, and was sunk on a north-dipping steplike pitch.

Veins of galena and sphalerite as much as 4 feet thick fill the pitch and associated flats. The main productive ore zone was in the cherty Prosser member from 135 to 150 feet below the shaft collar.

A shaft several hundred feet southeast of the Big Horseshoe mine in the south part of Agnies Patch produced a large quantity of galena. This older mine was also called the Little Horseshoe.

Red Dog mine (pl. 1, no. 197).—The Red Dog mine, in the SE¼ sec. 12, T. 3 N., R. 3 W., was operated by the Platteville Exploration and Development Co. from 1902 to 1905. The log of the first prospect drill hole on the property is recorded in the 1903 field notes of U. S. Grant, and shows 8 feet of zinc ore in the uppermost Platteville beneath the Spechts Ferry member. An excellent decription of the mine is given by Bain (1906, p. 117–118). Probably the ore that appeared in the drill hole in the Platteville was not reached by the shaft, as Bain states that all the mining was done in the Prosser member of the Galena dolomite, 50 feet below the collar of the shaft.

FAIRPLAY SUBDISTRICT

The Fairplay subdistrict (pl. 1) is in the vicinity of Sinsinawa Mound due west of the Hazel Green-Shullsburg subdistrict. It includes the Fairplay diggings in the south half of this area, the Shawneetown diggings in the N½ sec. 20, T. 1 N., R. 1 W., and the Lower Menominee and Upper Menominee diggings in the north part of the area.

These galena deposits were commercially important in the ninteenth century. A record of the production from these mines, although very incomplete, indicates that at least 24,500 tons of about 80 percent lead concentrate was mined.

Lead deposits at the Upper Menominee diggings were discovered by James Boice in 1827, and those at the Fairplay diggings probably in the eighteenth century. The Menominee diggings were abandoned by 1870, but operations in the Fairplay diggings continued until about 1900, and have been sporadically renewed since then.

A good description of these lead mines is in the report by Whitney (1862, p. 259–276).

All the known ore deposits are in the Galena dolomite. A little sphalerite was found in a few of the gash-vein lead deposits in the early 1900's. Prospecting completed to date has not found any ore (Kelly, 1948), and the scarcity of the usual alterations normally associated with the deeper ores, for example, solution-thinning and dolomitization, does not make this subdistrict very promising for deeper ores.

[90] Assay by Vinegar Hill Zinc Co.

The upper two thirds of the Galena dolomite, Maquoketa shale, and dolomite at Lower Silurian age are exposed in the vicinity of Sinsinawa Mound. The lower part of the Prosser cherty member is thin-bedded, fossiliferous limestone which closely resembles the McGregor member of the Platteville. Likewise the Decorah formation is mostly limestone rather than dolomite as is common farther east in the district. The Spechts Ferry shale member and the Quimbys Mill member are 5 and 4 feet thick, respectively.

The subdistrict lies on the gentle south limb of the Meekers Grove anticline. A syncline (pl. 8) that trends N. 30° W. passes through Sinsinawa Mound, and apparently this depression partly accounts for the existence of this erosion remnant of Silurian rocks.

Fairplay Level mine (pl. 1, no. 206).—This large and formerly important lead mine is in the N½SE¼ sec. 26, T. 1 N., R. 2 W. The mine opened by an adit at the west end trends east and in 1876 was 2,200 feet long. It was probably extended to a much greater length after that year. It was operated by the Fairplay Level Co., from 1868 until sometime after 1876, perhaps into the 1880's. A good description of it is given in the report of Strong (1877, p. 704).

BEETOWN SUBDISTRICT

The Beetown subdistrict (pl. 7) is the westernmost large and important mining area. It includes the formerly very important Muscalunge lead mines on Rattlesnake Creek about 3 miles west of Beetown, the Nip and Tuck diggings about 2 miles west of Beetown, and the main lead mines at Beetown and 2 miles to the east of that settlement. The more isolated Hackett's diggings are about 2 miles to the north, and the Black Jack or Beetown zinc mine is about 2 miles to the southeast.

Other mining areas of less importance in the western part of the mining district in Wisconsin (pl. 1) are: (1) the Cassville diggings along the tops of the Mississippi River bluffs in the vicinity of Cassville, Wis.; (2) the Lancaster diggings in the NW¼ sec. 6, T. 3 N., R. 5 W.; (3) the Goodenough diggings in the S½ sec. 34, T. 4 N., R 6 W.; (4) the very old lead mines along the Mississippi River at Glen Haven, Wis.; (5) the North Andover diggings in the SW¼SE¼ sec. 3, T. 4 N., R. 5 W.; (6) the Lower Magnesian diggings in sections 22 and 24, on the Little Grant River 6 miles east of Bloomington, Wis.; (7) the Hurricane diggings northwest of Hurricane in sec. 30, T. 4 N., R. 3 W.; (8) the formerly important Pigeon diggings on Pigeon Creek, 3 miles southwest of Lancaster, Wis., mainly in secs. 17 and 20, T. 4 N., R. 3 W.; (9) the Grant River diggings in secs. 23 and 14, T. 4 N., R. 4 W.; (10) the Boice Prairie diggings, mainly in the NW¼ sec. 36, T. 4 N., R. 3 W.; and (11) the Grab diggings in sec. 19, T. 4 N., R. 2 W., 2 miles northwest of Ellenboro, Wis.

The Beetown lead deposits were discovered about 1827, abandoned because of dangers from the Indians in 1829, and reopened in 1835. Very incomplete records indicate that at least 6,000 tons of 80 percent lead concentrate was produced from 1827 to 1876. The geology of the lead deposits has been described on page 129.

Only four zinc mines have been operated near Beetown, but zinc was mined at the Pigeon diggings in the form of smithsonite, and later in the form of sphalerite at the Coon Hollow mine (Bain, 1906, p. 117), northwest of Hurricane, and in the Grab diggings. Other small zinc deposits, similar to the known ones, probably will be found.

The uppermost part of the Prairie du Chien group, the St. Peter sandstone, the Platteville and Decorah formations, and most of the Galena dolomite are exposed in the subdistrict. The Ion member of the Decorah formation contains more green shale layers and is more limy than farther to the east. The Guttenberg member, where unaltered, is about 14 feet thick; the Spechts Ferry member has thickened westward to about 6 feet. The Quimbys Mill member of the Platteville formation has thinned to about 1 foot.

The subdistrict is crossed by folds, many of which trend N. 55°–75° E. and have amplitudes of 40 to 100 feet (pl. 7). Two major faults are known within the subdistrict, the largest of which is filled with a sandstone dike.

Black Jack mine, Beetown zinc mine, or Wilcox diggings (pl. 1, no. 209).—This mine (pl. 7, mine no. 30), in the SE¼ sec. 32, T. 4 N., R. 4 W., was opened and operated in 1868 by a Mr. Wilcox, who discovered the ore body from surface indications. It was bought by the Ross Mining Co. of Mineral Point, Wis. in 1873–74 and operated as the Beetown zinc mine, probably until 1880–1885. It was reopened as the Black Jack mine in the early 1900's.

The mine is opened by an adit 500 feet long that was driven S. 55° W. into the hill from the west side of a small southward-running branch of the Grant River. At least 12 shafts and two other adits penetrate the arcuate ore body, and at one time a hand jig was operated on the property. A good description and map of the mine as it was in 1876 are given in a report by Moses Strong (1877, p. 696).

The only available production record states that up to 1877, $3,500 worth of lead ore had been mined, and 45 tons of smithsonite and 175 tons of high-grade sphalerite concentrate had been produced (Strong, 1877, p. 696). It is reported that the high-grade vein ore is worked out, but that some lower grade ore remains in the mine. A lot of mining was done after 1876 (pl. 7), and the total quantity of zinc and lead ore produced was probably large, at least 100,000 short tons.

Smithsonite and dark-brown sphalerite occur in thick veins along pitches and flats in the Ion member of the Decorah formation and lower beds of the Prosser cherty member of the Galena dolomite. Strong reports that the main flat of sphalerite is as much as 3 feet thick. The ore is accompanied by much galena, and some pyrite and marcasite and copper minerals. Some disseminated replacement sphalerite ore also accompanies the vein ore in the blue beds of the Decorah formation.

The arcuate ore body is reported to be at least 25 feet thick. It curves around the southwest end of a northeast-trending anticline. Complete shalification has altered the blue beds of the Ion to a bluish shaly residue, and the Guttenberg to a chocolate-brown shale as thin as 2 feet.

Favorable areas for prospecting are northeast of the mine on both flanks of the northeast-trending anticline that extends between the Black Jack and Yellow Jacket mines (pl. 7).

Beetown mine.—The Beetown mine (pl. 7), mine no. 29) lies north of the Black Jack mine near the east quarter corner of sec. 29, T. 4 N., R. 4 W. It was opened and operated briefly about 1904 by the Beetown Mining Co. Four shafts in a north line provide access to the zinc ore body. Not much ore was mined.

The mine is on a direct north extension of the Black Jack mine ore body and is connected to it at least by a body of iron sulfide. The ore is pale yellow sphalerite, accompanied by an abundance of pyrite, marcasite, and platy white barite. The ore is in the Decorah formation and the deposit is very probably structurally similar to the Black Jack ore body.

It is reported that good zinc ore was found in 2 or 3 drill holes located across the public road a few hundred feet northeast of the mine.

Atkinson mine or Muscalunge Level (pl. 1, no. 207).—This large old lead mine (fig. 93), in the southern part of the Muscalunge diggings (pl. 7) in the S½SW¼ sec. 26, T. 4 N., R. 5 W., was opened about 1856 by Atkinson and Company, and was operated from that time until at least 1880. It was reopened about 1906 by the Muscalunge Prospecting and Development Co., but the amount of mining done, if any, is not known.

Descriptions of the mine in 1876 are given by Strong (1877, p. 698) and Chamberlin (1882, p. 459–462, atlas, pl. 15).

The mine is accessible by an adit called the Muscalunge Level and 4 shafts on the east side of Rattlesnake Creek. The main shafts, from southwest to northeast, have the following depths: Discovery Shaft, 57 feet; Middle Shaft, 92 feet; Upper Shaft, 110 feet; and Brinkman or Maiden Shaft, 153 feet. The mine contains at least 9,650 feet of old drifts and narrow stopes between and along the main mineralized joints and openings. Most of the stopes are 4 to 20 feet high and 4 to 10 feet wide (Chamberlin, 1882, fig. 26), and rock waste fills the stopes for several feet beneath the present floor.

From 1861 to 1876 about 1,020 tons of lead concentrate was produced from approximately 30,000 to 40,000 tons of mined ore (Strong, 1877). No pumping is necessary as the mine is above water table. The workings are very well cleaned out and not much galena was seen in the stopes, but some of the headings near the Maiden shaft are in ore. The mine was profitable in its earlier years, but lost money in the later ones.

North of the Atkinson mine is the even larger, but inaccessible, Graham lead mine (pl. 7, no. 4) (Strong, 1887, atlas pl. 15) from which some lead was mined in 1942. To the south is another lead mine of considerable size that was operated by Arthur and Co. in the 1870's and 1880's.

The ore body lies along the flank of a northeast-trending syncline. The galena is in gash veins in vertical and steeply inclined joints, and also cements tectonic and solution breccia openings along the joints in the Prosser cherty member of the Galena dolomite (Chamberlin, 1882, p. 459–461, fig. 25). The main ore-bearing opening is 77 to 95 feet below the top of the Prosser cherty member and is known locally as the "65-foot opening" formation. The openings, 4 to 10 feet wide, and 4 to 25 feet high, are controlled by two types of fractures: (1) inclined joints, most of which strike N. 60° E., and dip 60 to 70 degrees southeast, and (2) vertical joints that strike commonly N. 80° W. The ore is almost entirely galena, accompanied by a little marcasite and pyrite that are now mostly oxidized to limonite. No traces of zinc minerals were observed.

Yellow Jacket mine (pl. 1, no. 210).—This mine (pl. 7, no. 28), in the N½NW¼ sec. 33, T. 4 N., R. 4 W., is about 2 miles southeast of Beetown. It is an old zinc mine opened and operated between 1890 and 1905. Access to the mine was provided by a now-caved adit and 2 shafts in a ravine on the west side of the Grant River. The floor of the adit is on the top of the Spechts Ferry member.

The ore is disseminated sphalerite in the notably shalified Guttenberg member and blue beds of the Decorah formation. Galena, iron sulfide, and traces of chalcopyrite are present. The ore body is at the northeast end of the same anticline that controls the Black Jack mine to the southwest.

Eberle mine (pl. 1, no. 208).—The Eberle mine (pl.

7), in the SW¼ sec. 21, T. 4 N., R. 4 W., was operated about 1904 (Bain, 1906, p. 117). Two shafts, 60 and 100 feet deep, were sunk on an eastward-trending vertical joint. A gravity mill was erected and a small tonnage of ore produced. The ore came from the 60-foot level in the lower part of the Prosser cherty member. The 100-foot level is reported to be in the Quimbys Mill member. The workings are 150 to 200 feet long, and 8 to 15 feet wide. Near the west end a joint containing some galena in gash-veins was worked for about 50 feet in a N. 60° E. direction. The main ore is sphalerite and much marcasite cementing breccia in a large "opening" along joints.

FENNIMORE SUBDISTRICT

The Fennimore subdistrict (pl. 1) surrounds the city of Fennimore, and consists of two separate groups of lead mines, both in the Prosser cherty member of the Galena dolomite. The larger group is in sec. 18, T. 6 N., R. 2 W., and the smaller one is in the SW¼ sec. 22, T. 6 N., R. 2 W. A brief description of these old lead mines is given by Percival (1856, p. 57).

To the southeast in the NW¼ sec. 14, T. 5 N., R. 2 W., are very small groups of lead diggings on the top of the ridge about 1 mile southeast of Stitzer, Wis. They are in the Decorah formation, and in the Prairie du Chien group.

MIFFLIN-COKERVILLE SUBDISTRICT

The Mifflin-Cokerville subdistrict consists of nearly 40 square miles in which lead and zinc have been produced in the vicinity of Mifflin, Wis. The geology of part of the subdistrict is shown in plate 2, and another part in figure 202; see also Heyl, Lyons, and Agnew (1951, fig. 3).

The most important lead deposits in the subdistrict during the nineteenth century were the Crow Branch diggings (Heyl, Lyons, Agnew, 1951), and the Black Jack diggings in the immediate vicinity of Mifflin (fig. 16). Many other lead deposits formerly of considerable importance commercially are scattered throughout the general area.

Zinc mining began in the area in 1864, at the Black Jack or Penitentiary mine, and has continued with occasional interruptions until the present time. The Coker mines are among the largest mines in the district. Many of the mines near Mifflin and Rewey were operated between 1940 and 1957. The subdistrict has been far from adequately prospected for new zinc deposits, or extensions of the known ones. Many of the zinc and pyrite-zinc deposits in the western part of the subdistrict contain so much iron sulfide that they may some day be a source of this compound for pyrites or sulfuric acid.

All the workable deposits are found in the Galena dolomite and the Decorah and Platteville formations. The upper part of the Galena dolomite has been removed by erosion. The stratigraphy is very similar to that of the Platteville area except that locally the McGregor limestone member of the Platteville formation can be divided into two units, an upper one that consists of greenish gray medium-bedded limestone and dolomite about 15 feet thick, and a lower one that consists of about 17 feet of thin wavy bedded limestones, light gray in color, fine grained, sublithographic, with interbedded gray, greenish, and brownish shale partings. Both of these units as well as the other units containing limestone beds, may be locally dolomitized, owing to alteration caused apparently by the influx of magnesia by the ore-bearing solutions. The St. Peter sandstone and the uppermost beds of the Prairie du Chien group are exposed in the deeper valleys (pl. 2, and Grant and Burchard, 1907).

The south and west parts of the Mifflin-Cokerville subdistrict exhibit nearly the maximum of structural deformation found in the district. However, the central and eastern parts have about the normal magnitude of deformation, but the magnitude diminishes rapidly northward, so that along the north fringe of the subdistrict it is at a minimum for the district.

The largest fold is the Mineral Point anticline (pl. 8), which follows along the south boundary of the subdistrict to Arthur, Wis., where it branches, the main part turning north to Crow Branch and then west to the Platte River. This fold has an amplitude of 100 to 120 feet and a steeper north limb. It is bordered along the north limb from the Crow Branch diggings westward by a zone of reverse faults from a few feet up to at least 30 feet of displacement that dip steeply southward. North of this anticline is the complementary first-order Annaton syncline that strikes eastward through the area. This syncline is bowed slightly to the south just north of Mifflin, Wis., and from the apex of this southward bow a branch syncline swings off S. 65° W. and contains the Coker mines. Crossing the apex of the southward bow of the main syncline is the N. 43° W.-trending Mifflin fault (pl. 2), which has been previously described (p. 37, 58).

The subsidiary folds strike east, northeast, and northwest. The zinc ore bodies occur along the flanks of the folds and in the fractures zone along the Mifflin fault, and are controlled by these structures.

Zinc ore is generally found both in veins and disseminations, and the ore bodies are controlled by bedding-plane and reverse faults. Most of the vein ore, which is relatively rich in iron sulfide, occurs in the part of the subdistrict west of Mifflin, Wis.; and the disseminated ore, quite lean in iron sulfides, is found mostly east of Mifflin. Barite in abundance, and some copper minerals are found in some of the galena deposits along the south fringe of the subdistrict.

Last Chance and LaFollette mines (pl. 1, no. 211).—The Last Chance mine (pl. 22), operated for a short time in 1943 and 1944, is a southeast extension of the old LaFollette mine, and is in the NE¼NW¼NE¼ sec. 3, T. 4 N., R. 1 W. The mine was operated on a small scale by Hird, Myers, Weittenhiller, and Wisdom. At the base of the 40-foot shaft a crossdrift to the north and to the south connects two narrow, parallel ore bodies of S. 65° E. trend. The south limb is part of the workings of the old LaFollette mine, which was operated about 1910.

No record of the production from the LaFollette mine exists. Production of the Last Chance in the 1943–44 period was small and the ore is reported to have averaged about 9 percent zinc and 1 percent lead. Only a very little water had to be pumped.

The beds exposed in the mine are the uppermost McGregor member; the Quimbys Mills, Spechts Ferry, and Guttenberg members; and the blue beds of the Decorah formation. The ore is localized along a series of small folds trending N. 65° W., and, in the south limb, along a few thin vertical fractures of the same strike.

In the north limb ore body the ore occurs as a thin flat of sphalerite and iron sulfide in a bedding plane about 2 feet above the base of the Guttenberg limestone member. Barite is in the shaly residue phase of the Guttenberg. A zone of disseminated crystals of sphalerite is near the floor, just above the base of the Guttenberg member.

In the south ore body the ore consists of veins of sphalerite and marcasite in curved flats. In both the north and south ore bodies the iron sulfide is more abundant near the mine walls.

A thin vein of galena is in the shaft about 5 feet above the top of the Guttenberg. This ore zone in the Ion was mined extensively in the LaFollette and Washburn mines in 1910.

The U. S. Bureau of Mines drilled 5 holes near the southeast end of the mine and found ore in one hole, probably along a nearly vertical pipe or fracture (Lincoln, 1947). Much of this ore was in the Platteville formation.

Washburn mine (pl. 1, no. 214).—This zinc-lead mine is in the SE¼SW¼SE¼ sec. 34, T. 5 N., R. 1 W. Three shafts and an incline enter the general mineralized body. In 1906 the Washburn mine was opened by an incline, 500 to 600 feet long, and operated by the Washburn Mining Co. About 1910 a shaft was sunk west of the small brook, and the mine was operated apparently successfully until the end of that year. The company concentrated their ore in a small jig mill. In 1926 a shaft was sunk several hundred feet east of the incline, and a little mining was done. In 1940 a third shaft was put down by Austerman and Sheffler, about 150 feet southwest of the second shaft, and the mine was operated briefly during that year.

The jig concentrate from the Washburn mine averaged between 30 and 35 percent zinc.[91] Much lead and some iron sulfide concentrates were also shipped. Austerman and Sheffler produced ore which is reported to have averaged 12.8 percent zinc, 1.84 lead, and 17.28 percent iron.

The ore body trends N. 65° W. and is at an average depth of 40 to 50 feet, in the Guttenberg member. The face of the mine is reported to be about 150 feet wide and about 4 to 6 feet high.

The ore is in veins in flats in the Guttenberg, and is quite rich in iron sulfide. Much galena, some copper minerals, and some barite accompany the ore.

Crow Branch mine (pl. 1, no. 213).—Deposits of lead ore at Crow Branch (fig. 94), in the SE¼ sec. 22, and the NE¼ sec. 27, T. 5 N., R. 1 W., were discovered, probably in the 1830's or 1840's, and produced lead and zinc ore almost continuously until the latter part of the nineteenth century. About 1905 the Ross Mining Co. prospected for zinc ore on the property by drill holes, some of which are reported to have penetrated ore, and by 2 prospect shafts, one at the southeast end and the other at the northwest end of the deposit. In 1949 the Dodgeville Mining Co. drilled the deposit and some of their drill holes are shown on figure 94.

Good descriptions of this mine and the extent of the workings can be found in the early reports on the district (Percival, 1856, p. 34–36, 47–48, 61–62; Whitney, 1862, p. 361–364; Chamberlin, 1882, p. 481). The ore body is marked by old shallow diggings and larger shafts that trend N. 25° W. The area of old workings is ½ mile long and about 300 feet wide.

The production from this mine has undoubtedly been large, but the total produced is not known. Up to 1859, between 2,000 and 2,500 tons of lead concentrate had been produced (Hall and Whitney, 1862). No pumping would be necessary except in the lower workings in the Platteville formation if an old drainage tunnel would be reopened.

The ore deposits are unusual because deposits of lead, zinc, and iron sulfides are in all the beds from the Prosser cherty member of the Galena dolomite downward to and including the Prairie du Chien group, and a large part of the ore produced came from the Platteville formation.

[91] Data provided by C. W. Stoop.

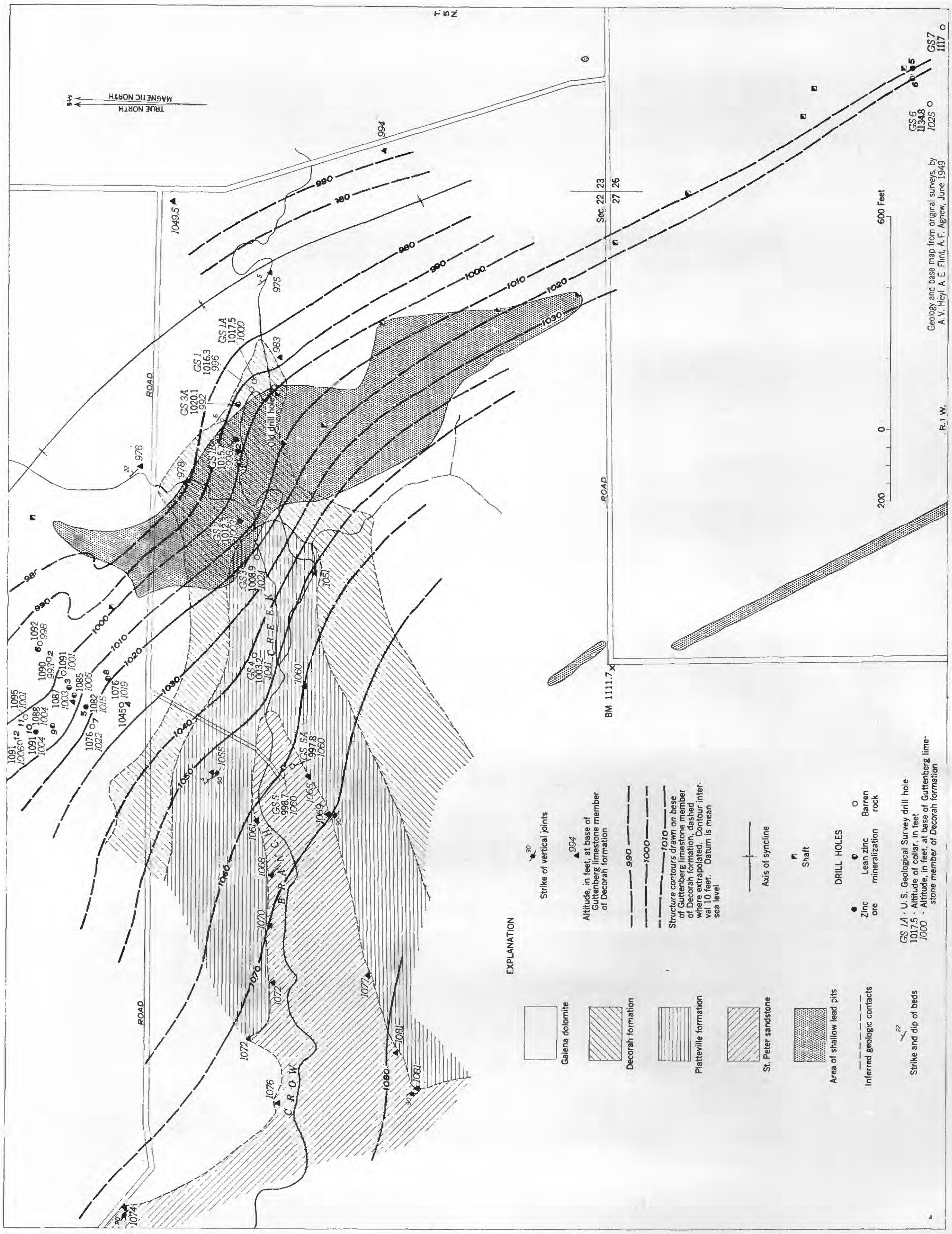


FIGURE 94.—Geologic map of Crow Branch mine area and drilling by U. S. Geologic Survey. Westward-dipping reverse fault zone is not shown, but lies between, and parallel to, the 1,000 and 1,020 contours.

The mineralized body includes a thickness of nearly 400 feet of beds (fig. 40), although probably only a small part of this thickness is rich enough in lead and zinc to be ore. The ore body is controlled by a zone of N. 25° W.-striking, southwest-dipping mineralized pitches and associated flats, on the southwest flank of a first-order syncline that borders the Mineral Point anticline, which lies to the southwest. (See also p. 141.)

The ore is in veins along the pitches and flats, and also as replacements. The ore is sphalerite and galena very rich in iron sulfide, and barite is locally abundant, mainly along the northeast edge of the ore body. Galena is most abundant along the southwestern edge, and is accompanied by much iron sulfide.

In 1949 the U. S. Geological Survey had drilled by contractors, Gillie Bros. and Frank Balcar, 10 holes across the trend of the Crow Branch ore body (figs. 94, 40, 54), to prospect the Prairie du Chien group. Ore was found in the Platteville and Decorah formations, and much pyrite and a little sphalerite in the St. Peter sandstone. Three mineralized zones of sphalerite and marcasite were encountered in the Prairie du Chien group in 2 drill holes (Heyl, Lyons, and Agnew, 1951, p. 8–9).

Possibilities for the discovery of additional ore in this very old mine are good, particularly if lead and zinc ore with an iron sulfide byproduct is desired. Little work was done here after 1880, and apparently by that time most of the old stopes were inaccessible or caved. All geologists who visited the mine earlier than 1880 mention the abundance of zinc ore in the deposit. Unless it has since been removed, large quantities of this zinc ore may remain in the stopes. The shaft farthest southeast, sunk by the Ross Mining Co., penetrated good vein sphalerite in the Prosser member of the Galena dolomite and in the gray beds of the Decorah formation. Not much work was done at this shaft, because of caving rock. However, drill holes in the vicinity of the shaft penetrated more iron sulfide than zinc sulfide. Northwest of the mine the structure swings sharply to the west. Some prospect drilling shows favorable indications in this direction, but the holes drilled by the U. S. Bureau of Mines (Lincoln, 1947) were bottomed at the base of the Decorah formation and are therefore not deep enough to cut the potential ore zone, in the Platteville formation. Drilling to prospect all the known mineralized zones in this area should go through the Prairie du Chien group.

Ebenezer mine (pl. 1, no. 228).—The Ebenezer mine (pl. 2), near the southwest corner of sec. 30, T. 5 N., R. 1 E., was operated from about 1905 to 1907. The shaft is 80 feet deep, to the bottom of the Spechts Ferry member. The zinc-pyrite ore body trends N. 60° W., and was mined along a length of 150 to 200 feet. The ore occurs in veins fairly rich in iron sulfide in the gray and blue beds and the Guttenberg member of the Decorah formation. The ore body lies on the north flank of the first-order syncline which contains the Coker mines farther northeast, and drilling to the east suggests that the Ebenezer ore body may possibly be a westward extension of Coker No. 2 ore body.

Coker No. 2 mine (pl. 1, no. 226).—The ore body that is now generally known as Coker no. 2 mine (pl. 2) includes Coker No. 2, Sunrise, Sunset, New Ellsworth, Dale-Rundell, Rundell, and Yewdall mines. It is in the SE¼ sec. 30 and the central part of sec. 29, T. 5 N., R. 1 E. The east end of the ore body was mined for galena in the nineteenth century. The mine was reopened for zinc ore in 1899 and operated through a shaft 65 feet deep by the Sunrise Mining Co. until about 1911, when the property was bought by the New Jersey Zinc Co. The Sunset mine was opened about 1905 by the Sunset Mining Co., and operated until about 1911, when it, too, was purchased by the New Jersey Zinc Co. The latter company mined the entire east half of the ore body as the Coker No. 2 mine until April 1926. The New Ellsworth mine was opened on the central part of the north limb of the ore body in 1910 by the Vinegar Hill Mining Co. and operated by them until January 1914. The Rundell mine was opened by the Vinegar Hill Mining Co. in January 1913 and operated by them until January 7, 1916. The Yewdall mine was opened by the Vinegar Hill Mining Co. in the latter part of 1916 and operated until October 1922. The Dale-Rundell mine was opened by the Vinegar Hill Mining Co. in the latter part of 1919 and operated until 1923. Coker No. 2 mine was reopened briefly in 1947 by the Inland Lead and Zinc Co. and ore was hoisted through the Dale-Rundell shaft.

The main Dale-Rundell shaft is 150 feet deep, to the Spechts Ferry member. The New Ellsworth shaft is 96 feet deep, to the Spechts Ferry. The Sunset shaft is 85 feet deep, to the gray beds of the Decorah formation; and the Sunrise shaft is 70 feet, into the blue beds of the Decorah formation.

The Coker No. 2 mine has an elongate, elliptical shape and a general N. 80° E. trend. The mine contains 12,000 linear feet of stoping and was mined to a width of 30 to 100 feet and to a height of 30 to 50 feet. Drilling has indicated that at the southeast end of the Dale-Rundell mine the ore body, rich in iron sulfides, turns sharply and continues due west for several hundred feet.

The total production from the Coker No. 2 ore body is about 1,700,000 [92] tons of ore. The Yewdall mine produced 350,000 tons of zinc ore; the production from the Sunrise and Sunset mines is not known; the Ellsworth mine produced 170,000 tons of ore averaging 9 percent zinc; the Coker No. 2 mine produced 875,000 tons of ore that yielded an average grade of 25.7 percent zinc jig concentrate; the Rundell mine produced 155,000 tons of ore averaging 10 percent zinc. About 300–400 gallons of water per minute was pumped. Considerable ore remains in the mine, and the Platteville formation in the mine floor has not been prospected for ore, even though Coker No. 1 mine produced lots of ore from the Quimbys Mill.

The main ore body is on the flanks of a N. 80° E.-trending anticline and is controlled by an elliptical pitch zone that dips into the anticline. The ore is in the lower part of the Prosser cherty member, and in the Decorah formation as veins fairly rich in iron sulfides along the well-developed flats and pitches. Smithsonite was produced from the upper levels.

Coker No. 1 mine (*pl. 1, no. 225*).—The ore body that is now commonly known as Coker No. 1 mine (pl. 2) includes also the Ellsworth or Coker (Bain, 1906, p. 101) mine and the Biddick mine. This very large ore body, in the N½ sec. 29, T. 5 N., R. 1 E., was discovered by deepening an old lead shaft in 1901 and was operated by the Coker Mining Co. as the Ellsworth mine until about 1908, when it was bought and operated by the New Jersey Zinc Co. until 1920 as Coker No. 1 mine. The Biddick mine at the west end was operated sometime between 1915 and 1920. The open cut at the east end of the mine was mined in 1947 by the Inland Lead and Zinc Co., and included ore in the Quimbys Mill member. Since 1951 the Mifflin Mining Co. has been operating in the mine, mainly in ore drilled by the U. S. Bureau of Mines, and in ore left in the old mine floor in the Quimbys Mill member. Operations were temporarily suspended in March 1955 when the mill burnt down, but were resumed briefly in 1957.

The main shafts are about 100 feet deep and the stopes are as much as 50 feet high. At each local northward bow in the main ore body is a branch that trends N. 10°–20° W.

In 1944 at the suggestion of the U. S. Geological Survey, the U. S. Bureau of Mines drilled to the northeast of the mine and discovered more ore (Lincoln, 1948). Some of this ore remains (1953) as well as ore elsewhere in the ore body. About 500 gallons of water per minute is pumped to keep the mine dry. The Coker No. 1 mine has produced more than 2,000,000 tons of ore to 1950, not including reworked jig tailings. From 1951 the Mifflin Mining Company is reported to have produced more than 200,000 tons of ore, much of it from the Quimbys Mill member.

The ore body lies along the north flank of a northeastward-trending syncline and is controlled by a northward-dipping pitch zone. A series of cross folds causes the northward and southward bows and the northward branches of the ore body.

The ore occurs in all the beds including the lower part of the Prosser member of the Galena dolomite, through the Decorah formation, down to at least the base of the Quimbys Mill member of the Platteville formation. It occurs in veins along the well-developed pitches and flats; it is leaner in iron sulfide than the ore of the Coker No. 2 mine. Furthermore, much disseminated ore is found in the Guttenberg strata.

New Dale Rundell mine (*pl. 1, no. 229*).—The New Dale Rundell mine (pl. 22) is in the SE¼NE¼ sec. 31, T. 5 N., R. 1 E. The ore body was discovered in drilling by the Vinegar Hill Mining Co. about 1915. After more drilling (Lincoln, 1946), the mine was opened in the spring of 1943 by the sinking of the shaft to a depth of 122 feet. Production started in June 1943, and the mine was operated by the New Dale Rundell Mining Co., until January 1944. It was reopened and mined briefly by the Inland Lead and Zinc Co. in early 1947.

In 1943–44 the mine produced ore averaging about 10 percent zinc. A considerable tonnage of ore remains at the northwest and east ends of the mine as shown in drilling (pls. 2 and 22), and additional ore might be found both east and west of its present (1953) known limits.

The mine lies on the south flank of a large N. 60° E.-trending syncline and is a westward extension of the Coker No. 3 and Senator ore bodies at the northeast (pl. 2).

The ore is in veins along the pitches and flats and is also disseminated in the Guttenberg and Quimbys Mill members. The disseminated ore is only in beds at and below the mine floor, and in the southwestward-trending prong, where it is rich in sphalerite and very lean in iron sulfide. The vein ore is in all beds of the Decorah formation, is relatively low grade, and is associated with very abundant iron sulfide, particularly at the east end of the mine.

Coker No. 3, and M. and A. or Big Tom mines (*pl. 1, no. 227*).—The M. and A. or Big Tom part of this ore body (fig. 95) is in the northwest corner of the NW¼-NE¼ sec. 32, and the Coker No. 3 part is in the S½SE¼ sec. 29, T. 5 N., R. 1 E.

The M. and A. mine was opened in the summer of 1912, and apparently was idle from then until about

[92] This information and that which follows furnished by the Vinegar Hill and New Jersey Zinc companies.

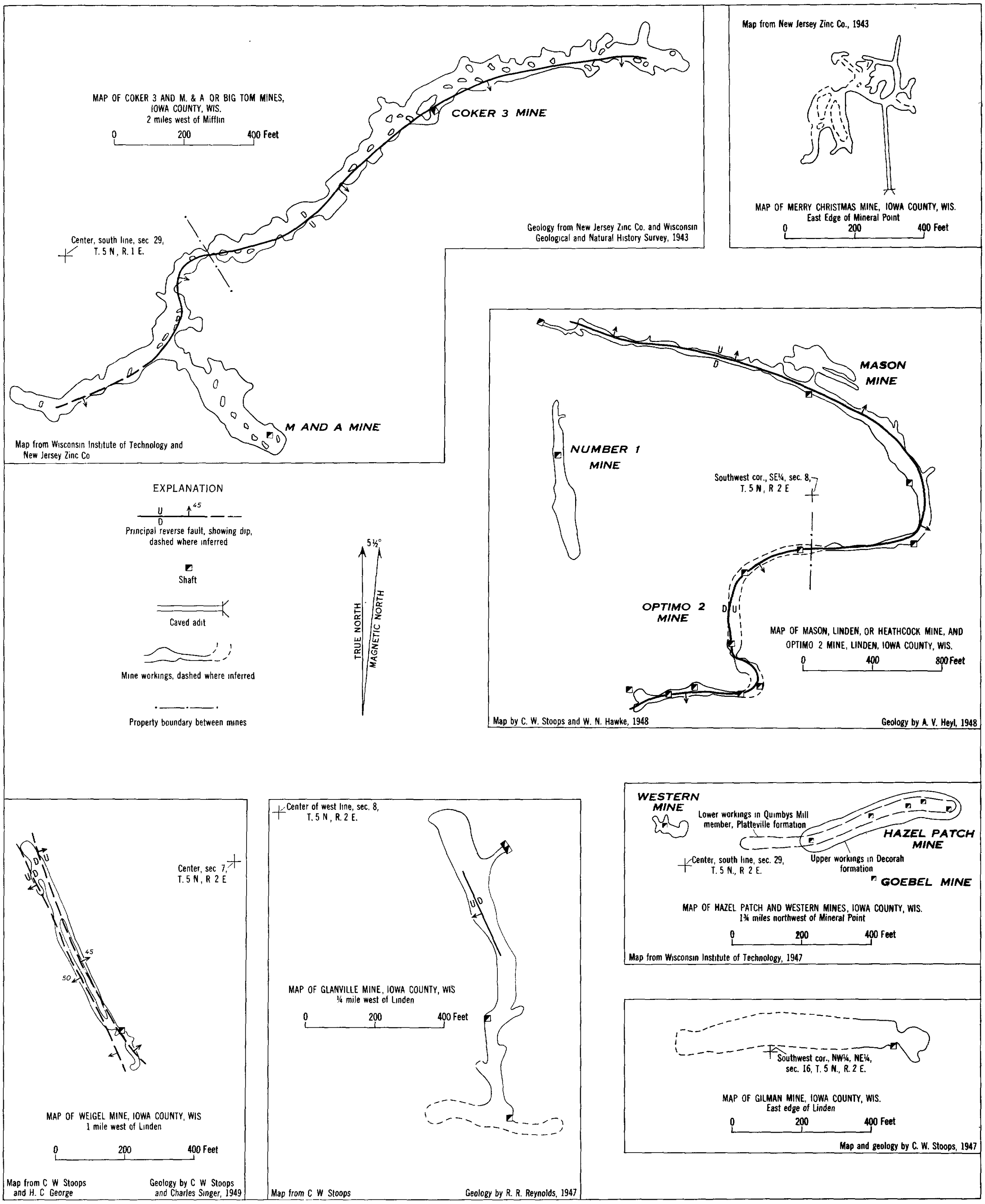


FIGURE 95.—Maps of Coker No. 3, M. and A. (or Big Tom), Merry Christmas, Hazel Patch, Western, Gilman, Weigel, Mason, Linden (or Heathcock), Optimo No. 2, and Glanville mines.

1916 (when it was reopened as the Big Tom mine) and operated until February 25, 1919. The Coker No. 3 mine was opened north of the road (fig. 16) about 1920 and was operated until March 13, 1926, by the New Jersey Zinc Co.

The production from this ore body is not known, but it probably was about 170,000 tons of zinc ore.[93] All the headings in the mines were reported to be in ore when abandoned, and there seems to be a good possibility of extending the known ore body. The ore averaged 7 percent zinc near the M. & A. shaft and yielded a jig concentrate of 45 percent zinc. About 125 gallons of water per minute was pumped to keep the mine drained.

The ore body has a 50- to 100-foot width, but only a 4- to 15-foot stope height. It is controlled by a N. 60° E.-trending pitch zone that dips to the southeast, and the ore body lies along the southeast flank of a second-order syncline.

The ore is in veins and disseminations mostly in the lower beds of the Decorah formation and the rest in the Quimbys Mill member of the Platteville formation. The vein ore is fairly rich in iron.

Senator mine (pl. 1, no. 224).—The Senator mine (fig. 16), in the north part of the SW¼SW¼ sec. 28 and the north part of the SE¼SE¼ sec. 29, T. 5 N., R. 1 E., is in a direct extension of the Coker No. 3 ore body (pl. 2).

The ore body was discovered in drilling by the D. D. and C. Mining Co. about 1907. Mining started in 1908, and the mine was operated until after 1910 by the Senator Mining Co. It was briefly reopened in 1916, and again in 1920, this last time by the Vinegar Hill Mining Co. in 1920.

The shaft is about 117 feet deep, to the Spechts Ferry member. The mine trends generally N. 80° W. and swings to S. 80° W. at the west end. The mine is 1,600 feet long, about 60 feet wide, and from 5 to 15 feet high, and lies on the south flank of a syncline.

The Vinegar Hill Mining Co. produced ore averaging about 10 percent zinc from the mine. The total production of the mine was reported to be about 50,000 tons of ore.

The ore body is controlled by a general eastward-striking, south-dipping pitch zone. The sphalerite ore is in veins, fairly low grade, and locally very rich in iron, particularly in the main flat at the toe of the main pitch in the Spechts Ferry and Quimbys Mill members. The ore is mostly in the lower Decorah.

Defense mine (pl. 1, no. 223).—The Defense mine (pl. 24), in the E½SE¼ sec. 28, T. 5 N., R. 1 E., was opened in June 1942 by the Defense Mining Co. and was operated until September 1945. The shaft is 78 feet deep, into the Quimbys Mill member.

The mine is reported to have produced 3,500 tons of ore that averaged about 6 percent zinc. Less than 100 gallons of water per minute was pumped to keep the mine drained.

The ore body occurs along the southwest flank of a slight N. 60° W.-trending syncline and is controlled by a reverse fault zone dipping 45 degrees toward the southwest.

The ore is mainly in veins along pitches and flats, particularly the latter, and is low grade owing to the the abundance of pyrite. Much of the pyrite is in large uniform and botryoidal masses (fig. 57). Marcasite is not a common mineral.

Possibly this ore body extends to the Senator mine, about half a mile to the west (pl. 2).

A disseminated smaller zinc ore body, of similar trend, which lies 800 feet north of the Defense mine, was drilled by the U. S. Bureau of Mines in 1944 (Lincoln, 1946). It was mined in 1946, 1947, and 1948 by the Mifflin Mining Co., who called it the New Defense mine, and reported production was 900 tons of 6 percent zinc ore.

Clayton mine (pl. 1, no. 222).—The Clayton mine (pl. 2), in the S½SW¼SW¼ sec. 27, T. 5 N., R. 1 E., was operated from about 1914 to 1916. The two shafts on the property form a northwest line; the northwest shaft is about 120 feet deep and the southeast one about 110 feet deep.

The zinc ore body trends N. 53° W. and has probably been mined for at least a 1,000-foot length and to a width of about 40 feet. It is a direct extension of the Defense mine ore body and is similar geologically to it. A few hundred feet of low-grade ore probably exists between the northwest heading and the Defense mine.

New Gruno mine (pl. 1, no. 221).—This mine (pl. 2), in the southwest corner of the SE¼SW¼ sec. 27, T. 5 N., R. 1 E., was opened and operated for zinc ore about 1914 to 1916.

The mine apparently produced a fairly large tonnage of zinc ore, but the total production and grade are not known except that the ore mined was very rich in iron sulfide.

The ore body appears to have a general eastward trend and is probably an extension of the Clayton ore body to the west; probably the two mines have been connected by workings or nearly so. The ore body is about 100 feet wide, but the height and length mined are not known, as the mine was not mapped until 1914, which was 2 years before it closed. The deposit is similar geologically to that of the Clayton and Defense mines, and the ore body is probably controlled by

[93] This and following data provided by New Jersey Zinc Co.

a similar fracture system of steplike flats and pitches.

Old Gruno or Miller mine (fig. 1, no. 230).—This zinc mine, in the NE¼NW¼ sec. 34, T. 5 N., R. 1 E., was opened and operated by the Miller Mining Co., about 1900, and later by the Gruno Mining Co. until about 1912. The main shaft is about 100 feet deep, to the McGregor member. A good detailed description of the mine is given by Bain (1906, p. 98–101). In 1912 this mine was producing a jig concentrate averaging 35 percent zinc.[94]

The ore body is arcuate in shape, is controlled by a pitch zone that dips outward around the nose, and lies within a small basin.

Penitentiary or Black Jack mine (pl. 1, no. 231).—This very old mine (pl. 2) is southeast of the Old Gruno, in the NW¼NE¼ sec. 34, T. 5 N., R. 1 E. The ore body was first discovered about 1835, and is in one of the oldest mines in the northern part of the district. Before 1860 it was worked for lead ore, and afterwards for both lead and zinc ore. The mine was in continuous operation from 1835 to about 1910, a period of 75 years. Descriptions of this mine may be obtained from the following reports (Precival, 1856, p. 34, 61–62; Whitney, 1862, p. 360–361; Strong, 1877, p. 721–722; Chamberlin, 1882, p. 434–435, 473–475; Dugdale, 1900; and Bain, 1906, p. 98).

Old Slack mine (pl. 1. no. 220).—This small zinc mine (pl. 2) in the southeast corner of the SW¼ sec. 26, T. 5 N., R. 1 E., was operated by the Slack Mining Co. about 1906. There are 2 shafts, one of which is 18 feet deep, into the Quimbys Mill member. The ore body has been mined a length of at least 200 feet. It is reported that the mine was closed because the end of the ore was reached.

The ore body is unusual because it is deposited in the southeast part of the Mifflin fault, and occurs in the shattered zone, where a sudden 15- to 20-foot rise in the beds to the northeast of the zone probably indicates the vertical component of displacement of the fault. The ore is high-grade sphalerite in breccia and replacements within dolomitized Guttenberg and Quimbys Mill strata. Part of the ore is reported to be in a solid vertical vein. Calcite and a very little pyrite and marcasite are the gangue minerals.

The Mifflin fault zone was drilled to the southeast of the mine near two prospect shafts in the northeast corner of the NW¼ sec. 35 by the Inland Lead and Zinc Co. The drill penetrated a brecciated zone about 200 feet wide which is mineralized by iron sulfides.

Okay, Slack, Peacock, Lucky Six, and Squirrel mines (pl. 1, nos. 219, 218, 217, 216, and 215).—These mines (pl. 2) are described together as they are all in the same mineralized zinc and iron sulfide body, which extends from the center of the west line, sec. 26, S. 80° E. to the SE¼ sec. 25, T. 5 N., R. 1 E., a length of about 2 miles broken only by the Mifflin fault. Starting at the west end the mines are (1) the Okay (fig. 96) which was operated by the O. K. Mining Co. from 1909 to about 1911, and reopened from September 1943 to February 1944 by a second O. K. Mining Co. It was abandoned in 1944 when the headframe was destroyed by fire. (2) The Slack mine was operated by the Slack Mining Co. from 1907 to about 1916, and briefly reopened in 1950 by the Mifflin Mining Co. (3) The Peacock mine was operated about 1906 to 1916. (4) The Lucky Six mine was operated about 1912 to 1918. (5) The Squirrel, which had the longest life of these mines, was operated from 1889 to about 1918, by Robert Young, John Wilkinson, George Wilkinson, George Clark, and James Young until 1909, and then by the B. M. & B. Mining Co.

The Slack, Peacock, and Lucky Six mines are probably all connected by workings, but there is about a quarter of a mile between the Slack and the Okay, and an unworked space of about 900 feet between the Lucky Six and the Squirrel.

The total production of ore from all these mines is probably between 400,000 and 500,000 tons. Prior to 1900 the Squirrel mine produced 2,500 tons of high-grade hand-cobbed zinc concentrate and 250 tons of lead concentrate (Dugdale 1900). In 1912 the concentrates of the Slack and Squirrel mines averaged 50 percent zinc and those of the Lucky Six and Peacock 40 percent zinc.[95] All of these mines operated fairly successfully, and some were very profitable. The Okay mine is reported to have produced 10 percent zinc ore while operated in 1943–44, and its west heading is in ore. The mines were relatively dry and only small quantities of water were pumped.

The ore bodies are all between 100 and 200 feet wide, and about 6 feet thick. They lie within a N. 80° W.-trending syncline on the south flank of a large westward plunging anticline that trends N. 70° E. The ore bodies are controlled by bedding-plane faults in the Quimbys Mill, Spechts Ferry, and Guttenberg members and by small, tight normal and reverse faults that trend N. 80° W., and are very little mineralized. The Mifflin fault passes between the Okay and Slack mines, which are probably in displaced parts of the same ore-bearing structures. The ore is in rich disseminations, replacements, and less commonly in veins. It is high-

[94] Data provided by C. W. Stoops.

[95] Data provided by C. W. Stoops.

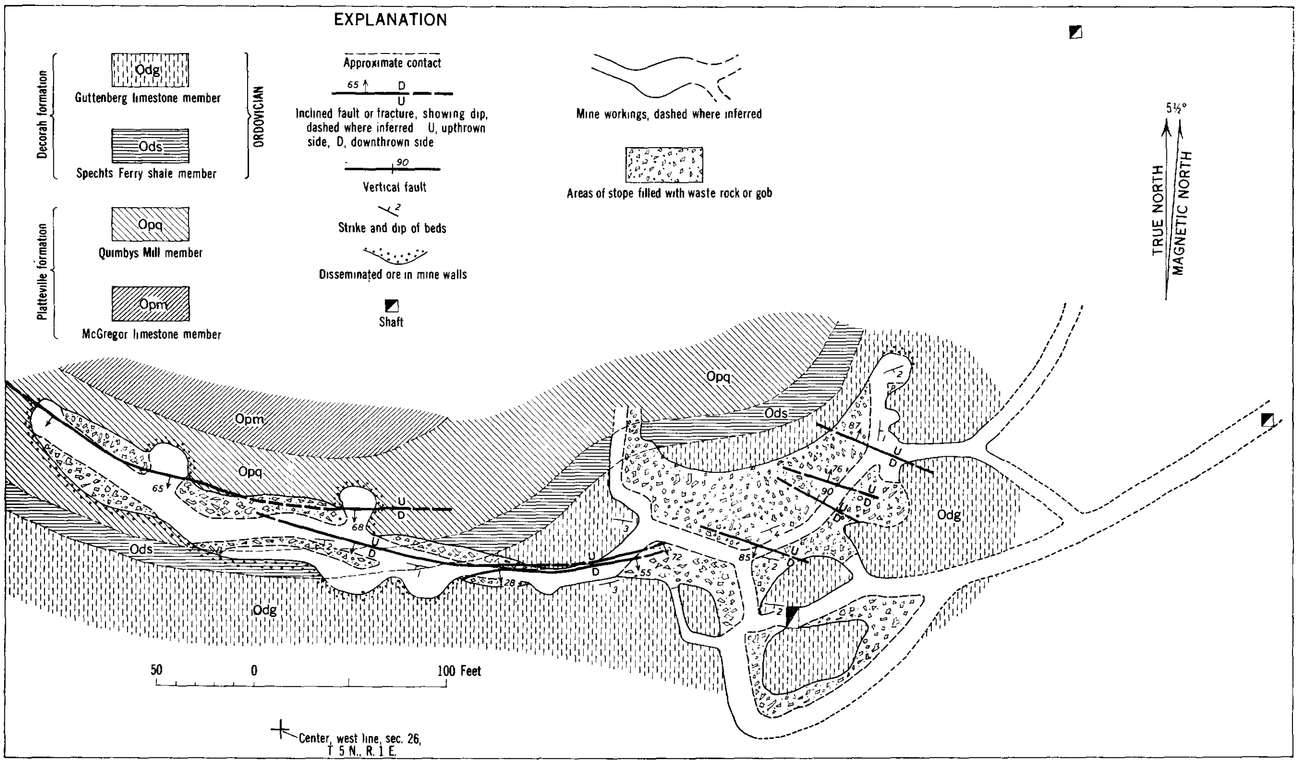


FIGURE 96.—Map of the Okay mine.

grade sphalerite ore, very lean in iron sulfides. Locally, much galena accompanies the zinc ore. The Peacock and Squirrel mines have branches similar geologically to the main ore body.

Nigger Jim diggings (*pl. 1, no. 212*).—This lead-barite deposit is in the NE¼SW¼ sec. 22, T. 4 N., R. 1 E., about 3 miles southeast of Rewey. The mine workings trend nearly east and show galena, and much barite. The access shafts are less than 50 feet deep and terminate above the water table.

At the suggestion of the U. S. Geological Survey the deposit was drilled by the U. S. Bureau of Mines in 1947–48 (Apell, 1949). Galena and abundant barite were found both in large enough quantities that they might be successfully mined. Calcite and a very little sphalerite and chalcopyrite accompany the ore. The ore is in veins, in breccia, and replacement of the wall rocks, which include McGregor and Quimbys Mill member of the Platteville formation and the blue beds and Guttenberg member of the Decorah formation. In all respects, this ore deposit resembles the typical pitch-and-flat zinc deposits except that galena and barite are the principal minerals.

Several similar lead-barite deposits that have been little prospected are known in the vicinity, and indications at the Nigger Jim ore body are good that the known ore body can be enlarged by more prospecting.

MINERAL POINT-LINDEN-DODGEVILLE SUBDISTRICT

This large subdistrict in the northeastern part of the mining district was formerly very important for its production of zinc and lead. The entire area contains lead deposits, but the main centers of concentration of ore deposits are at Linden, Dodgeville, and Mineral Point, with less important centers at Lost Grove, Diamond Grove, and at Van Matre's Survey or North Survey area. East of Dodgeville an extension of the subdistrict is traceable along Military Ridge, through the former settlement of Porter's Grove, west of Ridgeway, where locally heavy concentrations of lead and some zinc ore are present in the Galena and locally in the Decorah formations, thence east again by scattered lead deposits to Blue Mounds, a distance of about 15 miles. To the west and northwest of Dodgeville and Linden the subdistrict is connected by lead deposits to the Mifflin-Cokerville, the Montfort, and the Highland subdistricts. Detailed descriptions of Mineral Point-Linden-Dodgeville subdistrict in the lead- and early zinc-mining days may be obtained from older reports on the district, (Percival, 1856; Whitney, 1862; Strong, 1877; Grant, 1906; and Grant and Burchard, 1907, Hotchkiss and Steidtmann, 1909).

All the workable lead, zinc, and copper deposits occur in the Galena, Decorah, and Platteville formations, and for nearly a hundred years the Quimbys Mill member of the Platteville formation has been successfully exploited for galena, sphalerite, and smithsonite.

The uppermost beds of the Galena dolomite have been removed by erosion except east of Mineral Point (Grant and Burchard, 1907), and in many places only the middle and lower members of this formation remain. Locally, in the deeper valleys, the St. Peter sandstone is exposed, and in places the upper strata of the underlying Prairie du Chien group are exposed near Mineral Point and Dodgeville.

A few miles east of Mineral Point and Dodgeville all the normally limestone members of the Platteville and Decorah formations are fine-grained dolomite. The main thickness variations are, as elsewhere in the district, in the Quimbys Mill and Spechts Ferry members. The Quimbys Mill member thickens toward the east from about 8 feet at Linden to about 10 or 12 feet at Mineral Point and Dodgeville. The Spechts Ferry member, which is 1 foot thick at Linden, thins to a few inches of greenish argillaceous shale at Dodgeville and is nearly absent at Mineral Point. It is probably completely lacking farther east.

The southern half of the subdistrict shows a moderate degree of deformation. The trends of the first-order fold are east and northeast. The Mineral Point anticline, which has a structural relief of about 50 feet in this part of the district, passes northeastward from Lost Grove at the southwest edge of the subdistrict, where it splits into two parallel branches that join again north of Mineral Point (pl. 8). Between the two branches is a local N. 65° E.-trending, canoe-shaped syncline, of about 50-foot structural relief. A first-order syncline follows along the north side of the Mineral Point anticline, and a branch syncline passes N. 80° E. through the North Survey area, and thence through the southern part of the Dodgeville area. North of this branch syncline the area shows a minimum amount of deformation. Most of the minor folds have east, northeast, and northwest trends, the latter commonly N. 10°–20° W. In the vicinity of Mineral Point most smaller folds have a N. 60° E. trend, and amplitudes of about 30 feet. The ore bodies are controlled mainly by the smaller folds and faults.

An east-striking vertical fault of more than 30 feet displacement is exposed in a small quarry 4 miles east of Linden where Wis. route 39 turns south toward Mineral Point (Allingham, 1958).

Zinc ore is in veins along pitches and flats, and disseminated zinc ore is not uncommon. In this area, particularly near Dodgeville, the gash-vein deposits along mineralized joints typical of the upper part of the Galena dolomite are much less common. Many of the supposed gash-vein deposits mined for galena, especially in areas in which the Galena dolomite has been eroded, are in reality pitch-and-flat zinc-lead deposits from which the zinc has been removed by weathering or is present in the form of smithsonite. This is particularly true at Dodgeville and to a lesser extent at Mineral Point. For many years the smithsonite from such deposits was discarded; after 1860 it was recovered by reworking the old waste piles. For this reason abundant shallow diggings along the valleys at Dodgeville and Mineral Point are commonly an indication of the outcropping of zinc deposits rather than lead deposits.

In a large part of the subdistrict barite, chalcopyrite, and locally millerite are accessory minerals in the veins.

Copper was mined, from gash-vein deposits, principally from 1840 to 1860, east of Mineral Point and from the Quimbys Mill member south of Linden.

LOST GROVE MINES

John Vivian mine or Brown Range (pl. 1, no. 270).—This zinc mine is in the SE¼SW¼ sec. 33, T. 5 N., R. 2 E. at the site of Lost Grove village. There are a number of shafts here to the base of the Quimbys Mill member, which is at a depth of from 40 to 60 feet. The mine apparently had been operated at intervals from the early nineteenth century to about 1905. The zinc production from this mine is not large.

Most of the mining was in the Decorah formation and to lesser extent in the Quimbys Mill member of the Platteville formation. The ore is thin veins of sphalerite along the fractures in brecciated Quimbys Mill, and well-formed galena crystals; both are associated with much calcite and local iron sulfides.

Smithsonite was mined in considerable quantities from other mines in the vicinity of Lost Grove.

Earl, Kodatz, and Brown mines (pl. 1, nos. 233, 234, and 235).—These three small zinc mines are 2 to 3 miles from the nearest parts of the main Mineral Point-Linden-Dodgeville subdistrict. They were all operated during the promotional mining boom about 1906. They are in the E½ sec. 16, T. 4 N., R. 2 E., the Earl is southwest of the Kodatz, on the east side of U. S. highway 151; the Brown is northwest of the highway. The Earl shaft is 65 feet deep; the Kodatz is probably about an equal depth; the Brown shaft is 38 feet deep, into the McGregor member. The Earl mine was almost completely removed about 1954 in a relocation of U. S. Highway 151.

The Earl mine has an east trend and has been mined a length of 110 feet to a width of 25 feet. The sphalerite ore is in both vein and disseminated form, probably in the Quimbys Mill member; it is very rich in iron sulfide.

The Brown ore body is reported to have a width of 70 feet and the sphalerite to be in veins in flats just beneath the Quimbys Mill member.

The production of ore from these mines was very small, and the zinc deposit at the Earl mine was too lean in zinc and rich in iron to mine at a profit.

The deposits are important geologically, however, because they show that fairly well-concentrated zinc mineralization occurred in an area of sparse lead deposition at the fringe of the main northern part of the mineralized district.

Paul Graber mine (pl. 1, no. 236).—The Paul Graber mine, about a mile south of the Earl mine in the NW¼ sec. 22, T. 4 N., R. 2 E., was opened and operated by Paul Graber from February to September 1942. The shaft is 42 feet deep to the Quimbys Mill member.

In 1942 the mine produced a small tonnage of handcobbed ore that is reported to have averaged 27 percent zinc and 2 percent lead. Only a few gallons of water was pumped per minute.

The ore body has been mined in the east direction for a length of 80 feet. The zinc ore is in veins, is rich in iron sulfides, contains considerable galena, and is deposited in the Guttenberg member of the Decorah formation.

Drilling by Mr. Graber shows that the ore body continues in an easterly direction for at least a few hundred feet.

MINERAL POINT MINES

Hoare mine (pl. 1, no. 240).—This mine, in the center of the SW¼ sec. 6, T. 4 N., R. 3 E., was operated for galena and smithsonite from about 1875 to 1910 by Hoare Brothers. The ore body has an east trend and is traceable by old shafts and pits for half a mile. The waste piles indicate that large quantities of galena and smithsonite were mined; also, the piles contain large quantities of smithsonite that were not recovered.

The ore body is 100 to 200 feet wide. The ore was mined mostly from the blue beds of the Ion member, and a little from the Guttenberg member of the Decorah formation. Disseminated sphalerite in the silicified and shalified Guttenberg member is on the dump of one shaft. A little barite accompanies the ore. The Quimbys Mill member has not been prospected here. It may very possibly contain mineable zinc sulfide ore, because it is below the water table.

Liverpool or old Ross mine, Harrison Ranges (pl. 1, no. 232).—The Liverpool or old Ross mine is in the northeast corner of sec. 1, T. 4 N., R. 2 E. in the western part of Mineral Point. Galena and smithsonite were mined from the earliest mining days until 1908. The shallow mines were known originally as the Harrison Ranges and they were later mined by Mr. J. J. Ross and the Mineral Point Mining Co. during the eighteen seventies. Ore is reported to have been mined from the Decorah and Galena formations, and from all of the Platteville formation including the Pecatonica dolomite. Descriptions of these deposits may be obtained from the reports by Whitney (1862, p. 358–359) and Strong (1877, p. 735–736).

One of the ore bodies was reopened as the Liverpool mine in 1906 and operated until about 1908. The Liverpool shaft is 90 feet deep. The sphalerite occurs as 4- to 8-inch veins. The ore body has a general east trend.

Ben Hur mine (pl. 1, no. 239).—This zinc-lead mine, in the SW¼NW¼ sec. 5, T. 4 N., R. 3 E., was opened and operated during 1905–06 by the Ben Hur Mining Co. Three shafts are in a northerly alinement; two are about 65 feet deep and the third 20 or 30 feet deep. The ore body was mined apparently for a length of 100 to 200 feet on a north trend.

The waste piles show abundant smithsonite and some clusters of large galena crystals from the Prosser member of the Galena dolomite. Some vein and disseminated sphalerite was apparently mined in the deepest workings. The ore is very rich in iron sulfide.

Merry Christmas mine (pl. 1, no. 273).—The Merry Christmas (fig. 95) is one of few large sphalerite mines at Mineral Point. It underlies the eastern part of Mineral Point Hill, where the original discovery of lead ore was made at that town about 1825 and much early mining was done between 1830 and 1855 along Mineral Point Branch. The largest mine, in the SW¼SW¼ sec. 32, T. 5 N., R. 3 E., was opened as the Merry Christmas about 1906 when a 550-foot haulage adit was driven north into the hill to drain still older lead and oxidized zinc ore workings. It was operated with some interruptions until about 1911, when it was bought by the New Jersey Zinc Co., and was operated by them until 1912. It was closed, according to reports, because of a fatal rock fall.

The ore body is irregular in shape but appears to be somewhat arcuate with a nose pointing toward the northwest. The ore is sphalerite in veins and disseminated in the Guttenberg and blue beds of the Decorah formation. Galena is abundant in the Prosser strata of the Galena dolomite.

Harris mine (pl. 1, no. 274).—The Harris zinc mine, in the southeast corner of the SW¼SE¼ sec. 32, T. 5 N., R. 3 E., was opened by the Harris Mining Co. about 1908 and operated until after 1910. It was reopened in 1917 and operated until the mill burned down in that year.

The main mine entrance is a 45° incline extending down into the center of the southwest side of the ore body; a few old shafts penetrate the ore body at the northwest end. The ore body has a N. 80° W. trend which at the incline turns to a N. 60° W. trend. It is about 500 feet long, 35 feet wide, and 5 feet high. The floor of the mine is about 60 feet below the surface.

The mine produced possibly as much as 5,000 tons of 4 to 5 percent zinc ore. Practically no pumping was required and at the present time the mine is partially dry.

The ore is sphalerite as disseminated crystals and thin veins impregnating and replacing the Decorah formation. The iron-sulfide content is very lean, but the ore contains possibly as much as 1 percent copper in the form of chalcopyrite that may be recoverable as a byproduct. It is reported that the east mine heading still shows a face of mineable ore.

Temby Copper mine, or Bracken mine (pl. 1, no. 238).—The Temby mine, southwest of the Harris, in the northeast corner of sec. 5, T. 4 N., R. 3 E., is on the old Kendall copper "range" that was opened and operated in the early 1830's. The mine was opened about 1842 as the Bracken mine, and operated until at least September 1844, and then reopened in the late 1850's and operated until after 1860 (Whitney, 1862, p. 366–369; Chamberlin, 1882, p. 570). The mine was again reopened probably between 1875 and 1880 as the Temby copper mine, and another attempt to open it was made between 1906 and 1909.

The mine has three shafts in an east line, the middle one is 600 feet from the west shaft; the east shaft is 700 feet. The east shaft is probably at least 130 feet deep, into the Quimbys Mill member.

More than 500 tons of hand-sorted 7 to 34 percent copper ore is known to have been produced from this mine between 1842 and 1880 (Chamberlin 1882); the total production, if known, would probably be much larger.

Although rocks from the Platteville, Decorah, and Galena formations are on the dump, most of the copper ore appears to have occurred in solution-breccia along an east-striking joint in the lower strata of the Prosser cherty member of the Galena.

Beach Copper mine (pl. 1, no. 237).—The Beach Copper mine is one of the very old copper mines in the district, operated probably from 1832 to 1850 by Curtis Beach, and in 1879 to 1880 by W. T. Henry.

The rich copper ore on the dumps suggests that this mine may have been successfully operated on a small scale in the early nineteenth century. The total production of the mine is not known, but it fed a furnace operated by Curtis Beach for a number of years.. The only recorded production is 16.4 tons of ore that contained 7 to 19 percent copper that was sold in September 1850 (Chamberlin, 1882, p. 571).[96]

The ore body trends N. 85° W., extends across the SE¼NW¼ sec. 4, and is reported to continue across the SW¼NE¼ sec. 4, T. 4 N., R. 3 E. Apparently the ore is along a series of vertical joints and openings. The main line of shafts is about 800 feet long, and mineable ore was obtained from a width of 30 feet, and several parallel copper-bearing joints are to the northeast.

The primary ore is chalcopyrite that is mostly altered to tenorite, chalcocite, malachite, and azurite. The ore occurs as small veins and as irregular masses filling vugs (fig. 54) in the Prosser strata of the Galena. A little smithsonite, some marcasite and much limonite accompany the ore. The north Wasley Copper ore body, in the N½SE¼NE¼ sec. 5, T. 4 N., R. 3 E., is probably an extension of this ore body.

Wasley Copper mine.—This copper mine is in the N½SE¼NE¼ sec. 5, T. 4 N., R. 3 E., and worked two parallel ore bodies of east trend. The south ore body lies a few hundred feet south of the north one. The mine was operated by James Wasley and Co. in the period 1838 to 1850.

In 1844 the mine produced 133 tons of hand-sorted ore that contained 20 percent copper (Hall and Whitney, 1862).

Geologically the deposit is very similar to that of the Beach Copper mine.

Pierson prospect.—A shaft about 50 feet deep was sunk in 1952 in the southeast corner of the NW¼ sec. 5, T. 4 N., R. 3 E. by the Cuba Mining Co. and D. H. and S. Mining Co. into the north part of a zinc ore body. Some development drifting was completed in 1953, but operations were suspended because of low prices for lead and zinc. On the McIlhon property to the north of the shaft, the north part of the ore body was drilled by the U. S. Bureau of Mines, in cooperation with the U. S. Geological Survey in 1943 (Terry, 1948). In 1956 the prospect was reopened as the Ivy mine by the Turner Construction Co. and produced lead and zinc ore on a moderate scale until late June 1957 when work was suspended again because of low market prices. The ore was shipped for concentration to the Eagle Picher Co. mill at Linden.

The McIlhon part of the ore body is mostly in the Decorah formation and consists of sphalerite, pyrite, marcasite, and some galena, chalcopyrite, chalcocite, and covellite. The copper minerals are most abundant near the top of the ore body in the Ion member and are

[96] In 1957, the writers found in the U. S. Census report for 1880 a record that the Beach Copper mine produced 9 short tons of metallic copper (18,087 lbs.) in 1880 from an unknown quantity of ore.

associated with iron sulfides. At the shaft the ore is dark brown sphalerite and galena in veins in the Decorah formation, and copper minerals were not observed.

The tenor of the McIlhon part of the ore body is given in the Terry report, but the ore was not assayed to determine its copper content, which was usually large for zinc ore bodies of the district, possibly exceeding 1 percent copper.

Ansley Copper mine.—This old copper mine is located in the N½SE¼ sec. 32, T. 5 N., R. 3 E. It is the locality where copper was first discovered in the district by Mr. Ansley in 1832 (Schoolcraft, 1834, p. 301). The mine operated from that year until after 1838.

More than 700 tons of hand-sorted ore was produced (Whitney, 1854, p. 309) that averaged about 20 percent copper.

The ore body trends N. 70° W., is 1,300 feet long, 14 feet wide, and 15 feet thick. It is controlled by a fracture that strikes N. 70° W. in the Galena dolomite.

The ore is in a shallow gossan and enrichment zone that contains limonite, chalcopyrite, malachite, and azurite in lumps up to 200 pounds in weight in loose rock and clay. Below a depth of 15 feet the fracture zone contains clay with only a little ore scattered through it.

Chief of Police mine (pl. 1, no. 241).—The Chief of Police mine, near the center of the NE¼NE¼ sec. 8, T. 4 N., R. 3 E., was opened about 1909 and was operated until about 1910.

The shaft is approximately 40 feet deep, into the Guttenberg member. The ore body has a northwesterly trend and has been mined for a length of 200 feet (about 83 feet southeastward from the shaft and 115 feet northwestward).

The production was very small. When the mine was closed, the northwest end of the deposit was too lean to mine profitably, but the southeast face is reported to contain good ore. The mine was closed when one of the miners was seriously injured by blasting. Very little water was pumped.

The ore body is only 6 to 8 feet wide and about the same height. The sphalerite is disseminated and in veins in the upper Guttenberg and basal blue beds of the Decorah formation, and contains considerable galena.

DIAMOND GROVE MINES

Hazel Patch and Western mines (pl. 1, no. 268).—This zinc mine (fig. 95), just west of the center of sec. 26, T. 5 N., R. 2 E., on a tributary of Spensley's (formerly Legate) Branch of the Pecatonica River was operated from about 1905 to the end of 1908. The main shaft is 115 feet deep, into the Quimbys Mill member. The mine has two levels, the upper one in the Decorah and the lower one in the Quimbys Mill beneath. The production from this mine is not known but was probably not very large.

The sphalerite ore in the upper level is in veins which are particularly rich in iron sulfide. Barite is an abundant accessory mineral in the veins.

The small Western mine and a line of old lead pits to the west mark the continuation of the trend, and show that the mineral deposit extends in this direction.

Tripoli mine (pl. 1, no. 266).—The Tripoli zinc mine, in the center of the SW¼NE¼ sec. 26, T. 5 N., R. 2 E., was opened in 1905 and operated successfully until early 1908 by the Tripoli Mining Co.; it was reopened during 1910 and closed probably in 1911. A good description of this mine is given by Bain (1906, p. 107–108).

P. M. mine (pl. 1, no. 267).—The small P. M. mine in the NE¼NW¼ sec. 26, T. 5 N., R. 2 E., northwest of the Tripoli mine was opened and operated in November 1942 by cleaning out an old 90-foot shaft; mining continued until September 1943 by the P. M. Mining Co. Most of the mine workings trend N. 73° W., but they turn due west at the west end and southeast at the east end. The shaft is 130 feet from the east end of the stopes. The stopes have a length of 300 feet, a width of 20 feet at the west end and 60 feet at the east end, and a height of 4 to 6 feet.

The mine is reported to have produced a few thousand tons 6 percent zinc ore from November 1942 to September 1943. Only a small volume of water was pumped.

The sphalerite ore is in veins in the Guttenberg member of the Decorah formation. At the northwest end the ore is of mineable grade and not too rich in iron sulfides, but at the east end the iron sulfides are very abundant, and this abundance led to the abandonment of the east heading. The mine is controlled by a pitch that strikes N. 70° W. and dips toward the north. The beds dip 3 to 5 degrees southwestward.

Victoria mine or Advance mine (pl. 1, no. 265).—This small mine, in the SE¼SE¼ sec. 22, T. 5 N., R. 2 E., was opened in 1906 and operated until about 1908, possibly by the Advance Mining Co. The ore body trends N. 70° W., and is possibly on the trend of the P. M. ore body. Two shafts were sunk about 400 feet apart; the northwest shaft is about 50 feet deep and the southeast one about 60 feet, both to the Spechts Ferry member.

The ore is disseminated galena and sphalerite in the Guttenberg member. Iron sulfide is abundant at the northwest shaft.

Argall mine (pl. 1, no. 269).—The Argall lead-zinc mine, in the NE¼NE¼ sec. 28, T. 5 N., R. 2 E., was opened and operated about 1905–06 by the Essex Mining Co. on an old lead "range". There are several shafts 45 or 50 feet deep. Most of the workings consist of northward-trending drifts connecting old lead ore stopes, from which zinc ore was mined.

The ore body trends easterly and consists of two parallel parts about 60 feet apart; the northern part is 20 to 30 feet wide and the southern one about 60 feet wide. They follow the axis of a syncline. The waste piles contain large quantities of smithsonite and disseminated sphalerite from the Guttenberg and blue beds of the Decorah formation, very lean in iron minerals. Copper ore is reported to have been mined from some of the old "diggings," but none was noted on the dumps.

The U. S. Bureau of Mines drilled a few holes on the property in 1943 that were unsuccessful in discovering additional ore (Berliner, 1948).

LINDEN MINES

Gilman mine (*pl. 1, no. 262*).—The Gilman mine (fig. 95) is an east-trending mine that is just north of the center of sec. 16, T. 5 N., R. 2 E. It was operated successfully during 1916, 1917, and probably 1918 by the Saxe Mining Co. The main shaft is 125 feet deep, into the McGregor member of the Platteville formation. About 1930–33 additional mining was done west of the main mine through a new shaft.

The ore averaged 10 percent zinc.[97] From January 1, 1917 to May 19, 1917 zinc concentrate averaging 33 percent zinc was produced.

The zinc-lead ore body is controlled by an east-striking, south-dipping pitch zone and associated flats. The ore is deposited throughout a thickness of 45 feet of strata from the lower part of the Prosser downward to the base of the Quimbys Mill, but the latter member is the main ore zone. Ore in the Quimbys Mill fills fractures between fragments of dolomitized and brecciated limestone, and it occurs in veins fairly lean in iron sulfides along well-developed pitches and flats; a large flat containing 6 to 9 inches of sphalerite is in the Quimbys Mill member. Millerite, and its oxidation products bravoite, violarite, and "honessite" are not uncommon associated minerals. This mine is the locality where "honessite" was first found.

The well-defined structure and east-trend of this ore body, plus the high grade of ore suggest that extensions of this deposit might be found to the east and west of the present mine workings. The Inland Lead and Zinc Co. found ore to the south by drilling in 1947. About 125 gallons of water per minute was pumped.

Gribble and Stevens (*Milwaukee*), *Ross, and East Glanville mines* (*pl. 1, nos. 258, 259, and 260*).—These successful mines are all in one zinc-lead ore body. The Ross mine is in the N½NW¼NE¼ sec. 16, the East Glanville mine is in the NE¼NW¼ sec. 16. The Gribble and Stevens mine, known also as the Milwaukee mine, are along the central part of the south line of sec. 9, T. 5 N., R. 2 E.

The Glanville is the oldest of these mines, and lead mining may have been started as early as 1875 in the valley of Peddlers Creek to the west of the main shafts. The larger-scale zinc operations began about 1905 and continued until about 1911 when the ore body was worked out. The Gribble and Stevens mine commenced operation in 1906 and continued until about 1911. Operations at the Ross mine started about 1905 and continued until after 1912. The Ross shaft is 86 feet deep.

Only incomplete production statistics of these mines are available, but is estimated that nearly 100,000 tons of zinc ore were produced. In 1912 a 30 percent zinc jig concentrate was shipped from the Ross. Only 100 to 200 gallons of water were pumped to drain the mines.

The ore body is roughly Y-shaped; the main branch points west from its center, and the 2 other branches east and northeastward. The northeastward branch extends north from the east end of the East Glanville mine for several hundred feet through the Stevens property and then east through the Gribble property. The ore body has a total length of about 1 mile, and averages 30 feet wide and 7 feet high. However, the East Glanville and a part of the Ross mine mined ore in the Quimbys Mill member beneath the upper ore body, and have two levels of stopes.

South-dipping pitches probably control the east-trending part of ore body, but the most ore is found in flats as veins from 4 to 6 inches thick. Much iron sulfide locally accompany the ore; and violarite, the alteration product of millerite, is a rare mineral in the Quimbys Mill member.

Trio or Pode mine (*pl. 1, no. 261*).—This mine, in the NE¼NE¼ sec. 17 and the NW¼NW¼ sec. 16, T. 5 N., R. 2 E., was started when some old galena and smithsonite shafts were reopened in 1905, and was operated until about 1909; it was later reopened by the Racine-Linden Mining Co. The main shaft is 85 feet deep, into the Quimbys Mill member.

The ore body has been mined by a length of 600 or 700 feet in a S. 70° W. direction. It lies on the south flank of a large eastward-trending syncline and is a direct extension of the East Glanville mine ore body across Peddlers Creek to the northeast. The sphalerite and galena ore is in veins and disseminated in the Quimbys Mills member lower beds of the Decorah formation.

[97] Data provided by C. W. Stoops.

Dark Horse-Optimo No. 1 mine (*pl. 1, no. 255*).—These mines, in the same ore body, are in the N½SE¼ SE¼ sec. 8, T. 5 N., R. 2 E. The ore body was discovered by drilling about 1906–07. The Pollard Mining Co. began mining about 1906, but the operation was not very successful. In 1909 the Optimo Mining Co. bought the Pollard mine and commenced mining; shortly afterwards this company bought the Dark Horse mine to the west, which had started mining in 1907, and continued successfully until after 1912. Both mines were later known as the Optimo No. 1 and were mined by the Frontier Mining Co. The Dark Horse mine was briefly opened in 1951–52 by Blainey and Kettner. The grade of zinc jig concentrates averaged 32 percent zinc in the year 1912.[98]

The ore body is more than 1,500 feet long and trends S. 30° W. at the southwest end. It turns due east at the Dark Horse shaft, continues easterly to the Optimo No. 1 shaft, and has an average width of 130 feet and a height of 6 to 48 feet. About midway from the Dark Horse shaft to the southwest mine heading is a branch about 70 feet wide that trends southward for 300 feet and then curves sharply around eastward to a N. 60° E. trend along which it extends for 250 feet.

The controlling structure in the curved part of the mine is an arcuate pitch dipping at 45 degrees toward the south and southeast. The main ore body is controlled by a northeast-trending pitch that dips to the northwest.

The zinc-lead ore is in veins in the Decorah and in the underlying Quimbys Mill; in the latter member the ore is mostly at the southwest end of the mine. The veins average 4 inches wide and occur along pitches and flats. Some smithsonite is in the upper parts of the pitches.

Treloar or Harmony mine (*pl. 1, no. 252*).—The Treloar mine is in the SW¼NE¼ sec. 8, T. 5 N., R. 2 E. The ore body was discovered by drilling by the Saxe Co. in 1917. In that year the Saxe Co. sank a shaft into the blue beds of the Decorah formation to a depth of about 100 feet, but, although some stoping was done, only a little marcasite and calcite were found. The mine was reopened in 1935 and the shaft was deepened into the Quimbys Mill member to a total depth of 114 feet. Some zinc ore was found in the Quimbys Mill member and in the blue beds of the Decorah formation but the mine was operated for only a short time.

Very little mining has been done on this ore body for reasons not known. Much ore is on the small mine dumps, and the zinc concentrate remaining in the jigs is high grade. The property appears promising, but should be check-drilled.

[98] Data provided by C. W. Stoops.

The ore body has an east trend and a length known by drilling to be over 1,000 feet; it is controlled by an east-striking, north-dipping pitch zone. The ore body is 100 feet wide and probably 20 to 25 feet high. The zinc ore is very lean in iron sulfide and is disseminated in the blue beds of the Decorah formation. Barite is common.

Two other shafts are on the property, a 60-foot one in the west-central part of the SW¼NE¼, the dump of which contains very good zinc ore in solution breccia in the Prosser, and a 90-foot one through the Quimbys Mill in the northwest corner of the SW¼NE¼ sec. 8, on the south edge of the Robarts ore body discussed later (p. 274). In the 90-foot shaft a vein of sphalerite dipping to the north was found at 30 feet. At a depth of 63 feet in the 90-foot shaft, a drift was run southward for 30 feet in the blue beds of the Decorah formation.

Wicks mine (*pl. 1, no. 256*).—The Wicks mine, in the SW¼NW¼ sec. 9, T. 5 N., R. 2 E., was opened and operated by William N. Smith and Priestly in 1916 after the zinc ore body had been discovered by drilling. It was operated until sometime in 1917, when it was closed, probably because the ore is relatively low grade and disseminated.

The shaft is 85 feet deep and centrally located to the workings. The mine workings trend N. 80° W. and are 280 feet long, 40 to 60 feet wide, and probably 6 feet high.

The ore body is a direct extension of the south limb of the Vial mine ore body to the east, and possibly is an extension of the Harmony ore body to the west.

The ore is disseminated crystals of sphalerite impregnating and replacing the Guttenberg member of the Decorah formation. The ore is very lean in iron sulfide and the zinc content of the ore ranges between 3 and 5 percent. Ore of comparable grade remains between the east heading of this mine and the west heading of the Vial mine.

Vial mine (*pl. 1, no. 257*).—The Vial mine (Cummings, 1948), east of the Wicks mine on the same ore run, is in the SE¼NW¼ sec. 9, T. 5 N., R. 2 E. The mine was opened and operated in 1939 by the W. E. Faithorn Mining Co., but was closed because of the disseminated nature and the relatively low grade of the zinc ore. A brief attempt to reopen the mine was made by the Pioneer Mining Co. in the latter part of 1943. The shaft is approximately 100 feet deep, to the Spechts Ferry member.

The ore body has two east-trending branches connected at the east end by an arcuate nose convex toward the east. The ore body is about 6 feet high.

The ore is disseminated crystals of sphalerite impregnating and replacing the Guttenberg and, in part, the blue beds of the Decorah formation. It ranges in grade between 2 and 7 percent zinc and is very lean in iron sulfides.

The unmined parts of the ore body and their relations to the workings are shown in the Cumming's report (1948).

Rajah mine (*pl. 1, no. 242*).—This small ore body in the SW¼SW¼ sec. 4, T. 5 N., R. 2 E., was discovered by drilling by the Rajah Mining Co. about 1909. In 1910 this company and the Trio Mining Co. sank the shaft about 90 feet, to the Guttenberg member. A second shaft was sunk about 200 feet N. 60° W. from the original one. About 1911 the property was bought by the New Jersey Zinc Co. and operated until after 1912.

The production from this mine is not known but it probably was not large and the ore was of fairly low grade. The zinc jig concentrates produced in 1912 averaged 22 percent zinc.

The ore body trends N. 60° W. and has been mined a length of at least 300 feet and possibly more.

The ore is a distinctive rosin-yellow sphalerite in large replacement crystals in the Ion member of the Decorah formation. The iron-sulfide content of the ore is very low, and barite accompanies the ore as an uncommon gangue mineral.

Spring Hill mine (*pl. 1, no. 253*).—This mine, operated and opened by the Saxe Mining Co. during the latter part of the period 1915–1920, in the NE¼SW¼ sec. 8, T. 5 N., R. 2 E.

The ore body trends N. 10° W. and was mined for a length of about 500 feet. The sphalerite ore occurs in the lower beds of the Decorah in veins and disseminations. The mine was not a very successful operation.

Spargo mine (*pl. 1, no. 264*).—The Spargo mine is in the S½S½NW¼ sec. 17, T. 5 N., R. 2 E. Some lead was mined here prior to 1900, and the mine was reopened as a zinc mine during the 1905–1910 period as the Spargo mine. It was not a successful operation owing to the abundant iron-sulfide in the zinc ore.

The ore body has a S. 80° W. trend and a known length of at least 800 feet. The ore is in the lower beds of the Decorah formation.

The ore body is very possibly a direct extension of the Optimo No. 2 ore body and of the Linden Range and therefore may be a guide to exploration for additional ore to the southwest.

Weigel mine (*pl. 1, no. 247*).—The Weigel (fig. 95), west of Linden, Wis., is in the SW¼NE¼ sec. 7 T. 5 N., R. 2 E. The ore body was discovered by prospect drilling by the Weigel Mining Co. about 1907. The mine was opened in the spring of 1908 and operated with some shut-downs until 1910. Owing to the loose nature of the mine roof and the low-grade ore, it was closed. It was reopened in 1916 and operated until July 1917 by the Saxe Mining Co., but was again closed owing to low-grade ore and to excessive mining costs.

The mine stopes are 6 to 25 feet high. The shaft is not deep enough to serve the whole mine, and there are at least 3 or 4 benches in the mine from the deeper north end to the south end, up which the water had to be pumped in stages.

The production of ore from this mine is between 10,000 and 100,000 tons. The jig concentrate averaged 30 percent zinc.[99] High mining and pumping costs, plus the low-grade ore, led to the closing of the mine.

The ore body is controlled by N. 25° W.-trending opposite-dipping pitch zones; the one along the southwest wall dips to the southwest, and the other dips to the northeast. The sphalerite ore is in veins in the pitches and flats in the Quimbys Mill member of the Platteville formation and the lower beds at the Decorah.

The northwest heading, when the mine was closed, is said to have a 4-inch flat of good zinc ore in the Quimbys Mill member. The southeast heading was too lean to mine at a profit. Prospecting on the trend toward the northwest and southeast has some promise.

Silver Dollar mine.—This small isolated zinc mine is in the NE¼ sec. 10, T. 5 N., R. 1 E. The mine was opened and operated briefly about 1903 in the center of a small group of old shallow lead mines. The shaft is over 100 feet deep to the Spechts Ferry member.

The ore is in large disseminated crystals of sphalerite that replace and impregnate the Decorah formation. The ore appears to be high grade, and very lean in iron sulfides.

The deposit is in an area of old lead mines about 4 miles from the nearest zinc mine, and is centrally located between the mining centers of Mifflin, Montfort, and Linden. The lead deposits are in the Galena dolomite, but the Decorah and Platteville formations have been very little prospected for zinc ores in the vicinity of the Silver Dollar mine.

LINDEN RANGE

The Linden Range is one of the first known, one of the longest, and largest lead and zinc ore bodies in the entire district. It is traceable continuously by stopes and known unmined ore, except for four short intervals along a sinuous length of more than 4 miles; and some of the mines were important producers for many years. The production of zinc and lead ores from the many mines in the ore body is probably at least 2,000,000 tons.

[99] Data provided by C. W. Stoops.

The ore body was discovered about 1833 by pioneer lead prospectors at the west edge of Linden, and the discovery led to settlement of the town.

Descriptions of the mines in this ore body from south to north follow.

Optimo No. 2, part of Mason mine (pl. 1, no. 263).—This mine (fig. 95), the southernmost of the mines on the Linden Range, is in the E½NW¼ sec. 17, T. 5 N., R. 2 E. It was operated by the Linden Mining Co., in conjunction with the Mason mine at the north, in the latter part of the nineteenth century. It was then operated by the Mifflin and Linden Mining Co. which was later absorbed by the New Jersey Zinc Co., and lastly was operated by the Optimo Mining Co. when it was called the Optimo No. 2 mine; the latter company operated it from about 1912 to 1915.

The production from this mine is not known but undoubtedly a considerable tonnage of high-grade lead, zinc, and zinc carbonate ore was mined.

The zinc and lead ore body is controlled by a pitch zone that dips generally to the south and east. The ore is in veins along the pitches and flats in the Decorah formation and to some extent in the Quimbys Mill beds. The ore is of a good grade, fairly rich in galena and contains some iron sulfide.

Toward the west along Hawke Branch, at the site of the Mineral Point and Northern Railroad station, are a shaft and mine known simply as No. 1 (fig. 95).[100] The shaft penetrates a N. 10° W.-trending ore body that was operated by the Mifflin and Linden Mining Co. prior to 1908. This ore body was mined in conjunction with Optimo No. 2 and Mason mines. It is apparently a northwestward-trending transverse ore body that extends between the limbs of the Mason-Optimo No. 2 horseshoe, similar to ore bodies found at Dodgeville (pl. 10).

Mason, Linden, or Heathcock mine (pl. 1, no. 254).—This very important old lead and zinc mine (fig. 210) is in the central part of the S½ sec. 8, T. 5 N., R. 2 E., connects directly with the Optimo No. 2 mine at the southwest, and continues toward the northwest nearly to the Glanville mine. Mining commenced here in 1833 and continued with some interruptions up to 1909, when it was closed by the New Jersey Zinc Co. Very good descriptions of this mine while it was in opration may be found in the earlier reports, as it was carefully studied by Strong (1877, p. 726-728), Chamberlin (1882 p. 450, 471-473), Bain (1906, p. 103-105), Percival (1856, p. 51–52), and Whitney (1862, p. 351–352).

Millerite, violarite, bravoite, and "honessite" (fig. 53) are accessory minerals in brecciated Quimbys Mill. The deposit is notable for the fact that ore and mining extended down through the Galena, Decorah, and Platteville formations into the basal beds of the Pecatonica dolomite member.

Glanville mine, also formerly Treglown and Captain Wicks, and Morrison diggings (pl. 1, no. 248).—The Glanville zinc mine (fig. 95) is in the NW¼SW¼ and the S½SW¼NW¼ sec. 8, T. 5 N., R. 2 E. It is in the northwest extension of the Mason or Linden mine ore body, and the Robarts mine is in the same ore body to the northeast. The north part, formerly the Treglown and Captain Wicks diggings, was discovered about 1840, and the south part, called Morrison diggings, about 1846. The Glanville mine was opened about 1901 and operated by Charles Glanville until about 1911, and then by the Saxe Mining Co. until 1917. The main shaft is 100 feet deep, to the base of the Quimbys Mill member. An open-cut was worked briefly during the 1930's in the east end of the ore body in the valley flat between this mine and the Mason mine. The north part of the mine was briefly reopened in about 1948 by John Airman, but as far as is known, no ore was produced.

Good descriptions of this mine may be obtained from the reports by Strong (1877, p. 729) and Bain (1906, p. 106–107).

There are at least three levels in the mine; the lowest is in the Quimbys Mill member. The ore in this level contains millerite, violarite, bravoite, and "honessite" in acicular crystal clusters up to an inch in diameter.

Robarts (Hinkle) and Wildcat or Lucky Six No. 2 mines (pl. 1, nos. 249 and 250).—The Robarts mine includes the Treloar, and Kickapoo mines and is in the NW¼ sec. 8, T. 5 N., R. 2 E. Like the Mason mine to the south in the same ore body, it is one of the very old mines in the district. The ore body is a third of a mile long, about 70 feet wide, and was worked by several levels. It was operated as the Robarts mine from the 1830's until about 1860 and then closed until 1869, after which it was worked fairly continuously until 1916. In the early nineteen hundreds it was operated by Thomas Hicks and after 1910 by the Frontier Mining Co. as the Hinkle mine. It was closed in 1913 and reopened by the Saxe Mining Co. in 1915 and operated by them through 1916.

The Lucky Six No. 2 or Wildcat mine is at the west end of the same ore body and was operated as late as 1920.

The Treloar (not Harmony, p. 274) was operated on a corner of the east end of the ore body about 1903. The Kickapoo is just north of this shaft on the north edge of the ore body where it passes east from the Hinkle property and was probably operated for the

[100] Carlson 1958 lists this mine as the "Depot mine", a name recently given to it by local residents.

most part before 1900, although some work was done between 1900 and 1916 without great success.

In 1953 the Davis Mining Enterprises built a small flotation plant, and by 1954 had reopened the east end of the Hinkle (and also the Treloar and Kickapoo) mine by a truck incline extending northward from a location about 300 feet southeast of the old Hinkle shaft. The mine produced briefly in early 1955, but not much ore was produced. It was purchased in 1956 by the Eagle Picher Co. and reopened and operated by them on a large scale until July 1957 when it was closed because of low market prices. The stopes extend eastward to nearly the southwest end of the Optimo No. 3 mine.

The production from this ore body is not known but it was undoubtedly large. In 1911 the jig concentrates averaged 30 percent zinc, in 1912 they averaged 25 percent zinc.[1] The Roberts mine was closed in 1916 because of the dangerous condition of the mine roof, and the long underground haulage from the east heading of the Quimbys Mill run made it too expensive to operate.

The ore body consists of sphalerite vein ore rich in galena in all the beds from the Prosser cherty member down to the base of the Quimbys Mill member. It is controlled by two pitch zones that strike east and dip outward on both sides of the ore body. The ore body lies within an eastward-trending syncline. Locally, the ore in the Quimbys Mill member contains a little millerite. Good descriptions of the ore body may be obtained from the earlier reports (Strong, 1877, p. 728–729; Chamberlin, 1882, p. 469–471; Bain, 1906, p. 105–106).

Probably good ore remains in the Quimbys Mill member west of the Hinkle shaft, in the vicinty of the Wildcat shaft, and in the east headings.

Optimo No. 3 or Rolling mine (*pl. 1, no. 251*).—The Optimo No. 3 mine (fig. 97) is northeast of the Robarts, in the NE¼NW¼NE¼ sec. 8, T. 5 N., R. 2 E. The zinc-lead ore body was discovered in drilling by the Linden Zinc Co.; that company opened the mine about 1915 or 1916; and operated it until 1917, and then sold it to the Rule Mining Co., which continued operations until at least 1921.

The shaft is 91 feet deep to the Spechts Ferry member.

The tonnage mined is not known, but in 1917 about 200 tons of ore per day was mined yielding 10 tons of 30 percent zinc jig concentrate.

The ore body was worked on four separate benches or levels; the lowest level is in the Quimbys Mill member at the northwest and the highest bench in the Prosser cherty member at the south near the shaft. The pitches are not well defined, but a low-dipping steplike pitch trends northeastward and dips northwestward. The ore is found mainly as veins in flats in four distinct zones between the lower beds of the Prosser and the base of the Quimbys Mill. The pitch zone was best developed in the gray beds of the Decorah formation. At the west end is a N. 45° W. transverse pitch.

Additional ore is developed: (1) to the southwest, where a large unmined ore body (1950), called the Kickapoo, extends 900 feet towards the Robarts mine; (2) at the east end of the mine a narrow extension of the ore body has been drilled for 250 feet east of the heading; (3) some ore remains in the mine floor of the lowest level at the southwest end of the mine.

South Rule, Optimo No. 4 (*Fearless*), *North Rule, and Prairie mines* (*pl. 1, nos. 244, 245, 246, 243*).—These zinc-lead mines are in the north part of the Linden Range ore body, and they were worked from 1923 to November 1932. The Optimo No. 4 or Fearless (fig. 97) was operated by the Optimo Mining Co., the North and South Rule mines (fig. 97) by the Rule Mining Co., and the Prairie mine (fig. 97) by the Badger Zinc Co. The South Rule mine closed in November 1926, the North Rule mine closed in 1930, and the Prairie mine operated from January 1930 to November 1932.

The actual production from these mines is not known, but it is estimated to have been between 500,000 and 800,000 tons of ore. The Prairie mine had the first flotation plant in the district. The grade of the ore is estimated to be between 5 and 10 percent zinc and up to 1 percent lead.

The part of the ore body that contains these mines is at least 10,850 feet long, 40 to 150 feet wide, and averages 15 feet in height. It is controlled by a well-defined pitch zone that dips generally westward or northward.

The gray and blue beds of the Decorah formation contain good vein sphalerite ore in the South Rule mine, ore in replacement-veins and disseminated replacements in the Optimo No. 4 mine, and lean disseminated ore in the North Rule mine; but north and east of this no ore is found in the Ion member. The gradual northward change from rich vein ore, to lean disseminated ore, to no ore in the Decorah is notable. Ore is not present at the South Rule mine in the Quimbys Mill member, but a little occurs at the Optimo No. 4 mine. The Quimbys Mill contains the main body of ore still farther north at the North Rule mine and the only ore at the Prairie mine. The ore in the Quimbys Mill occurs as veins in flats and fills the fractures of breccia. Barite is common at the South Rule, uncommon at the Optimo No. 4, fairly abundant at the North Rule, and very abundant at the Prairie mine. Arsenic

[1] Data provided by C. W. Stoops.

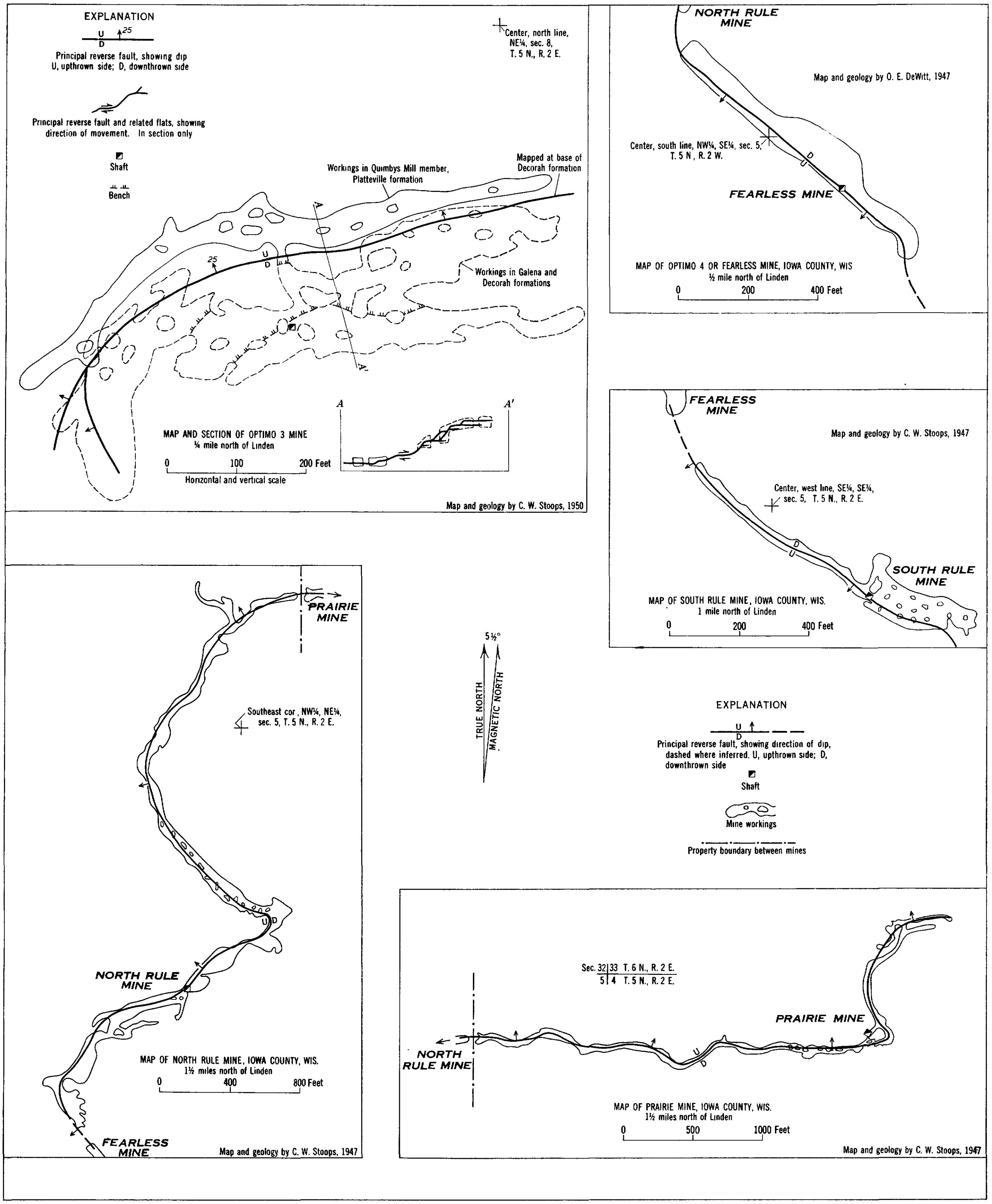


FIGURE 97.—Maps of Optimo No. 3, Optimo No. 4 (or Fearless), South Rule, North Rule, and Prairie mines and map and section of Optimo No. 3 (or Rolling) mine.

is present in small quantities in the ores, especially at the North Rule mine.

The mine headings at both the extreme southern and northeastern ends of the ore body contain good ore and an extension of the ore body in both directions appears favorable. Southeast of the South Rule mine the ore body very probably curves sharply to the west and connects with the Optimo No. 3 ore body.

NORTH SURVEY OR VAN MATRES SURVEY MINES

Joe Stegan mine or Duke Smith mine (pl. 1, no. 272).—The Joe Stegan lead mine is on both sides of an eastward-trending road along the line between sec. 7 and sec. 18, T. 5 N., R. 3 E. It is a large lead mine and one of the last in the district operated solely for lead. The deposit has been described by Strong (1877, p. 732). The western part of this deposit was apparently opened and operated during the first decade of the twentieth century as the Joe Stegan mine.

The mine is still accessible by an adit driven eastward into the ore body, north of the road. A drift extends S. 70° E. from the adit under the road into section 18 along a vertical fracture. Numerous small vertical northeastward- and northward-trending galena-bearing joints have been stoped to the north and south of this drift. A short distance south of the road the drift crosses a strong eastward-striking mineralized joint with a large opening that has been stoped for several hundred feet to the east and west. About 50 or 100 feet to the west of the intersection of the southeast and the east-west drifts, a cross-drift has been extended south for a considerable distance to cut two parallel, mineralized, eastward-striking fractures that have not been stoped to any extent. The mineralized opening along the main east-trending joint is about 15 feet wide and 20 feet high, and originally contained considerable ore.

The galena ore, which is quite free of iron and zinc minerals, is found in the lower part of the Prosser where it fills the cavities in a solution breccia and is deposited along the joints as large cubic crystals, locally known as "cog lead".

Barreltown adits.—Two adits were driven northward and southeastward from the north and south banks of a small stream tributary to Spensley's Branch in the NW¼ sec. 17, T. 5 N., R. 3 E. at the site of the former town of Barreltown by the Dodgeville Mining Co. in 1951. They were operated briefly in 1951–52 and the ore shipped to the mill of the Dodgeville Mining Co. for concentration. The mine was closed because of low lead and zinc prices. They were reopened again by that company in 1955 but were closed by 1957.

The ore is replacement crystals and veins of sphalerite and galena in the Decorah formation. It contains some pyrite and marcasite and a little chalcopyrite. A few gash-veins of galena were noted. The beds of the Decorah formation are dolomitized.

North Survey mine (pl. 1, no. 271).—The North Survey mine (fig. 98), in the NE¼SE¼ and SE¼NE¼ sec. 6, T. 5 N., R. 3 E., to the east of Spensley's Branch was operated by the North Survey Mining Co. from about 1916 to 1920.

The zinc ore body has been stoped to a height of 7 feet. The main shaft, at the north end, is 35 feet deep; the southern one is 80 feet deep. Both are to the base of the Quimbys Mill member.

The mine produced a reported 20,000 tons of ore that yielded a 26 percent jig concentrate. About 100 gpm of water was pumped.

The ore is at the base of the Quimbys Mill member, in a flat 1 to 2 feet thick that consists of about half sphalerite and half calcite, and a little iron sulfide, and some barite. The ore body lies within the part of the first-order northeastward-trending Annaton syncline extending from Linden to Dodgeville, Wis.

So far as is known both the north and southeast headings still contained mineable ore when, owing to the low market price in 1920, the mine was closed, therefore the extension of the ore body is probable. It is in an area of abundant shallow lead and smithsonite mines that have been little prospected for deeper sphalerite ores.

DODGEVILLE MINES

Dodgeville No. 2 (Hospital Run) and Dodgeville No. 3 mines (pl. 1, no. 282).—The Dodgeville No. 2 or "Hospital run" mine (fig. 98) is in the southeastern part of the city of Dodgeville, Wis., in the N½NW¼ sec. 34, T. 6 N., R. 3 E. The zinc-lead ore body was discovered by the Dodgeville Mining Co. in 1945, and the mine was opened in the autumn of 1945 by that company and closed in September 1949. The ore was milled at a 200 ton flotation mill at the Dodgeville No. 1 mine.

The shaft is about 105 feet deep, a few feet into the McGregor member of the Platteville formation beneath the Quimby's Mill member. About 100 gallons of water per minute were pumped to keep the mine dry. The mine consists of several interconnected northwestward and eastward-trending arcuate ore bodies. The stope height is between 6 and 7 feet.

Toward the southeast the Dodgeville No. 3 mine was operated by the same company briefly in 1949, and from 1950 until during 1952 in a similar ore body. The ore bodies in the Dodgeville No. 2 and No. 3 mines are controlled by several small N. 10° W.- and easterly-trending folds.

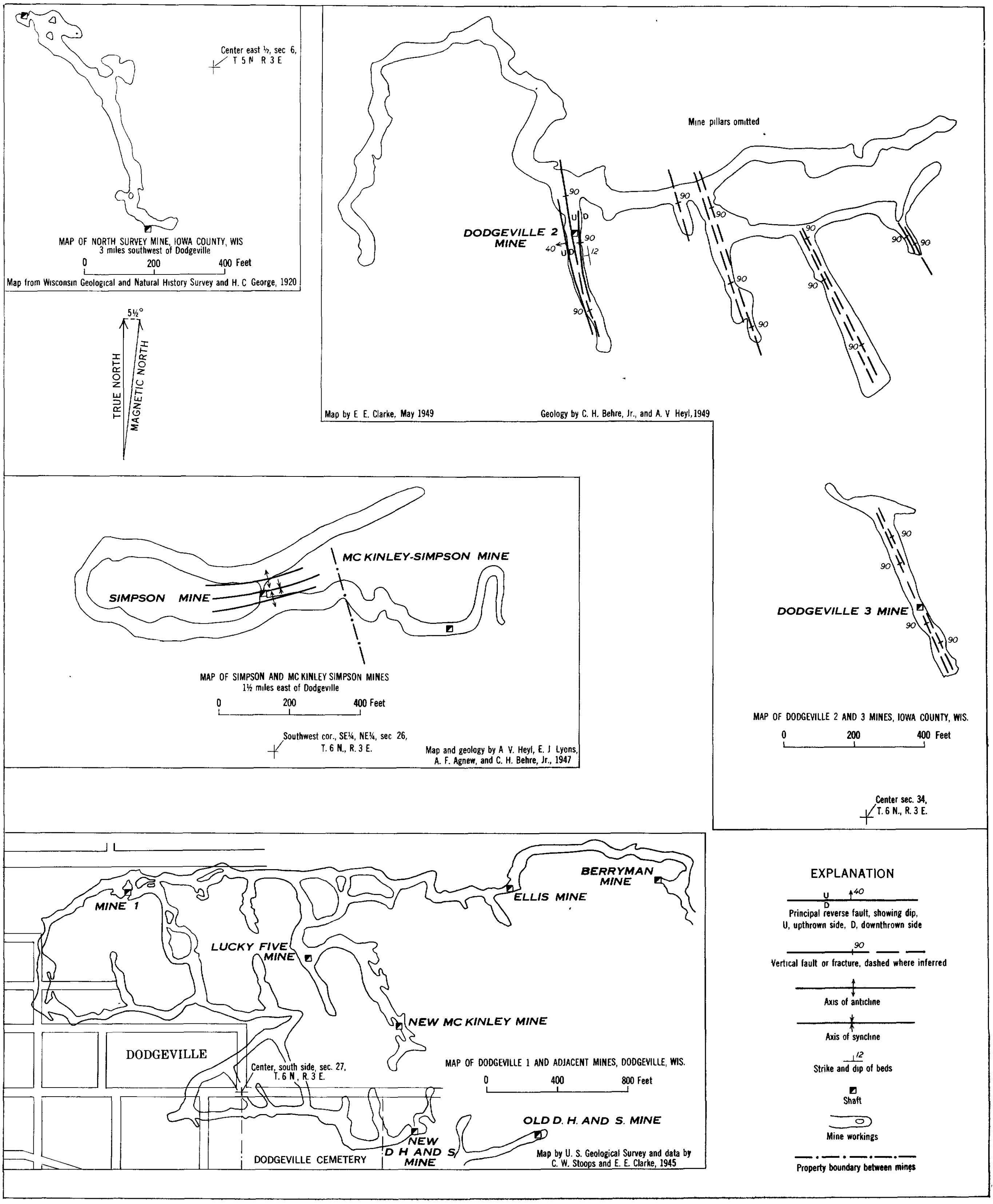


FIGURE 98.—Maps of North Survey, Dodgeville No. 2, Dodgeville No. 3, Simpson, McKinley-Simpson, and the Dodgeville No. 1 and its adjacent mines.

The ore in both mines occurs mainly as veins 1 foot thick of high-grade sphalerite with much galena, some marcasite, pyrite, calcite, and a little chalcopyrite. These veins are flats that fill bedding-plane faults in or just above the brown carbonaceous "calico" shale layer at the base of the Quimbys Mill member.

Along the east stope wall of Dodgeville No. 2 mine, at the shaft, the westward dip of the beds and also of the main bedding-plane fault near the base of the Quimbys Mill reaches an angle of 10–15 degrees; this marked dip is accompanied by small compressional vertical faults that strike parallel to the ore body. In addition to the main bedding-plane fault are several subsidiary ones, in places strongly slickensided, especially in the beds directly above the main fault. In vertical section these bedding-plane faults tend to fan outward from the uplifted beds at the east edge of the ore body; the principal fault follows the dip of the beds, but the upper ones cut horizontally across the downward-dipping beds. The slickensides on these fault planes strike N. 77° E. Near the west stope wall is a small reverse fault or pitch that strikes N. 10° W. and contains veins of lead and zinc sulfides. The pitch branches at a low angle from the main bedding-plane fault and curves upward to 70° at the roof of the mine, into which it disappears. Between the east wall and this pitch are several well-defined N. 10° W. vertical fractures that in places contain narrow veins of galena and sphalerite. A little shalified rock borders the main bedding-plane fault, and the Quimbys Mill member is locally brecciated and sheared. The solution thinning is much too small to produce the magnitude of structure seen in the mine.

Dodgeville No. 1 mine, includes New D. H. & S., Ellis, Berryman, Lucky Five, and New McKinley mines (pl. 1, nos. 281, 283, 280, and 279).—These successful zinc-lead mines (fig. 98) underlie most of the S½S½ sec. 27, and also the central part of the north edge of sec. 34, T. 6 N., R. 3 E. The 80-foot Dodgeville No. 1 mine shaft is near the center of the north line of the SE¼ SW¼ sec. 27; the New D. H. & S. shaft is 119 feet deep; the McKinley and Lucky Five shafts are about 60 feet deep; the Ellis shaft is about 75 feet deep and is in the NW¼SE¼ sec. 27. The Ellis and New McKinley mines were operated during the period 1926–1929 by the Rule Mining Co. and the McKinley Mining Co., respectively. Operations at the New D. H. & S. mine commenced in October 1942 and continued until 1948. Operations began in 1940 at the Dodgeville No. 1 mine; the mine was shut down in June 1945 when the ore body was considered to be mined out by the company. The 200 ton flotation mill on the property was used since then to mill ore from other properties owned by the company.

All the ore bodies were discovered by drilling, the drilling at the Ellis was done in 1924 and at the Dodgeville No. 1 mine in 1939.

The Dodgeville No. 1 group of mines produced as much as 350,000 tons of ore averaging approximately 3 percent zinc and about 1 percent lead.[2]

The mines are in a connected group of ore bodies, which consists of several connected east- and northeast-trending arcuate ore bodies crossed by a series of N. 10°–20° W.-trending ore bodies that are spaced about 300 to 500 feet apart. The geology of the ore bodies has been previously described (p. 109–115, 123–124; pl. 10).

The ore is sphalerite associated with considerable quantities of galena and more locally with iron sulfide and calcite. Barite is a common constituent in the northeastern part of the mine but uncommon or absent elsewhere.

Old D. H. and S. or Stratman mine (pl. 1, no. 284).—This mine (fig. 98) was operated from about 1940 to May 1942 by the D. H. and S. Mining Co. It is about 600 feet southeast of the New D. H. & S mine, in the NW¼NE¼NE¼ sec. 34, T. 6 N., R. 3 E., and is probably in the same ore body, although the stopes are not directly connected. In 1942 the mine is reported to have produced 10 percent zinc and 28 percent lead hand-cobbed concentrate.

Part of the stopes trend N. 25° W. and are controlled by the northwestward-trending folds and fractures. The geology is similar to that in the Dodgeville mine.

Pengelly mine (pl. 1, no. 285).—This old zinc-lead mine, in the extreme northeast corner of the SE¼NE¼ sec. 34, T. 6 N., R. 3 E., was operated about 1904–05. Bain (1906, p. 112) gives a description of this small mine.

McKinley mine (pl. 1, no. 286).—The McKinley mine, in the W½NE¼NW¼ sec. 35, and in the SW¼SW¼ sec. 26, T. 6 N., R. 3 E., was operated on a small scale by the McKinley Brothers more or less continuously from about 1903 (Bain, 1906, p. 112) until 1924. The shaft is 100 feet deep, to the top of the McGregor. The stopes of the mine are at least 3,000 feet long, averages about 40 feet wide and 6 feet high.

The zinc-lead ore body trends N. 25° W. at the shaft and extends northward from it for about 400 feet into section 26. There it turns to about N. 65° W. and continues to the west section line of the section, where it joins the workings of the Berryman mine (fig. 98), a direct extension of the Dodgeville No. 1 mine ore body. South of the shaft the ore body is reported to continue on the S. 25° E. trend for about 400 feet and

[2] Data provided by the Dodgeville Mining Co.

then turn sharply westward to the outcrop. The ore occurs as a flat vein of sphalerite and galena at the base of the Quimbys Mill member along a bedding-plane fault.

Tyrer mine (pl. 1, no. 287).—The Tyrer is a lead mine in the NW¼NE¼ sec. 35, T. 6 N., R. 3 E., about a quarter of a mile east of the McKinley mine. It was operated in 1904 and is briefly described by Bain (1906, p. 113).

Four S. and B. mine (pl. 1, no. 277).—The Four S. and B. mine, along the center of the north line of the SE¼SW¼ sec. 26, T. 6 N., R. 3 E., was operated by the Four S. and B. Mining Co. from about 1939 to the early part of May 1943.

The mine has an east trend and is more than 1,050 feet long, about 40 feet wide, and 6 feet high. Of this length 400 feet is west of the shaft and 650 feet to the east. About 350 feet east of the shaft the zinc-lead ore body turns S. 60° E. A N. 30° W. branch has been mined for 70 feet north of the shaft.

The ore body consists of a single flat of sphalerite and galena, lying just above the carbonaceous brown shale layer at the base of the Quimbys Mill member, and this flat extends along the full length of the mine.

To the south and east are numerous formerly important small lead and zinc mines. Among the best known of these is the Guthrie, which was operated in 1914–17.

Oxman or Oxman and Owens mine, and Snowball mine (pl. 1, no. 276).—The Oxman zinc, lead and zinc carbonate mine, in the N½SE¼ sec. 26, T. 6 N., R. 3 E., was operated from 1904 to about 1906. The ore body trends N. 80° E. and may be an extension of the Snowball mine ore body farther east. The shaft is 70 feet deep. Sphalerite, galena, and smithsonite were mined. Bain (1906, p. 113) describes the Snowball mine.

Simpson, McKinley-Simpson mines (pl. 1, no. 278).—The Simpson mine (fig. 98), in the S½NE¼ sec. 26, T. 6 N., R. 3 E., was opened in July 1945 and operated by the Dodgeville Mining Co. until 1947. The McKinley-Simpson is an older small zinc mine. The Simpson zinc ore body was discovered by drilling by the Dodgeville Mining Co. in 1942.

The Simpson shaft is about 100 feet deep, into the McGregor member, and it is midway between the two limbs of the mine, and a haulage drift connects it with the stopes 50 feet to the north and south, which are 6 feet high.

The mine produced more than 10,000 tons of 2.2 percent zinc ore that contained very little galena.[3]

The ore body is controlled by a widespread bedding-plane fault at the base of the Quimbys Mill member. The ore is a 4-inch vein of sphalerite in this fault plane just above the carbonaceous brown shale layer that marks the base of the Quimbys Mill member. Much marcasite accompanies the ore. The bedding-plane fault is traceable not only in the limbs of the ore body but between the limbs in the connecting haulage drift, though here it is not mineralized. A few slickensides on the fault plane indicate a N. 10°–20° W. movement, except that at the shaft some slickensides have a N. 60° E. strike.

Several very small eastward-trending folds extend through the mine. A gentle syncline of 2-foot amplitude passes across the north drift at the shaft, and the beds rise at the north and south to crests along the south edge of the north limb and north edge of the south limb of the ore body. Then they drop about 2 or 3 feet from these inner walls to the outside walls in each limb. A few very minor inclined and vertical fractures cross the ore body in a general easterly trend.

Williams mine (pl. 1, no. 275).—This, one of the oldest important mines for lead and zinc at Dodgeville, is in the SW¼SW¼ sec. 25, T. 6 N., R. 3 E. The ore body was discovered in 1844 and worked nearly continuously for galena, smithsonite (fig. 57), and sphalerite until 1909. The mine has been well described by Strong (1877, p. 730) and Bain (1906, p. 111).

Hugh Jones mine, and Hendy, Gavey, and Sobey & Co. mine (pl. 1, no. 288).—These very old, important lead and zinc mines are south of the Williams mine. The Hugh Jones is in the NE¼NW¼ sec. 36, and the Hendy, Gavey, and Sobey & Co. mine, in the same ore body, is to the west, in the NW¼NW¼ sec. 36, T. 6 N., R. 3 E. They were important producers in the 1860's and 1870's and were later worked to a minor extent by the Williams Mining Co. They are described by Strong (1877, p. 731).

Porters Grove mines (pl. 1, no. 289).—This group of lead mines is along the line between secs. 21 and 22, T. 6 N., R. 4 E., about 8 miles east of Dodgeville. The workings are confined to mineralized vertical joints that trend from due north to N. 15° W. and contain veins of galena as much as a foot wide. In addition to galena, smithsonite and sphalerite are present on some of the dumps and may have been produced. The lead and some of the zinc ore is deposited in about the middle of the Galena dolomite, but other zinc ore is deposited in the Decorah formation.

DEMBY-WEIST MINES

Demby-Weist mines.—The main mines, known as the Demby-Weist mines (fig. 99), of an isolated group of lead mines are about 12 miles northeast of Dodgeville in the northwest corner of section 28 and the southwest

[3] Data provided by the Dodgeville Mining Co.

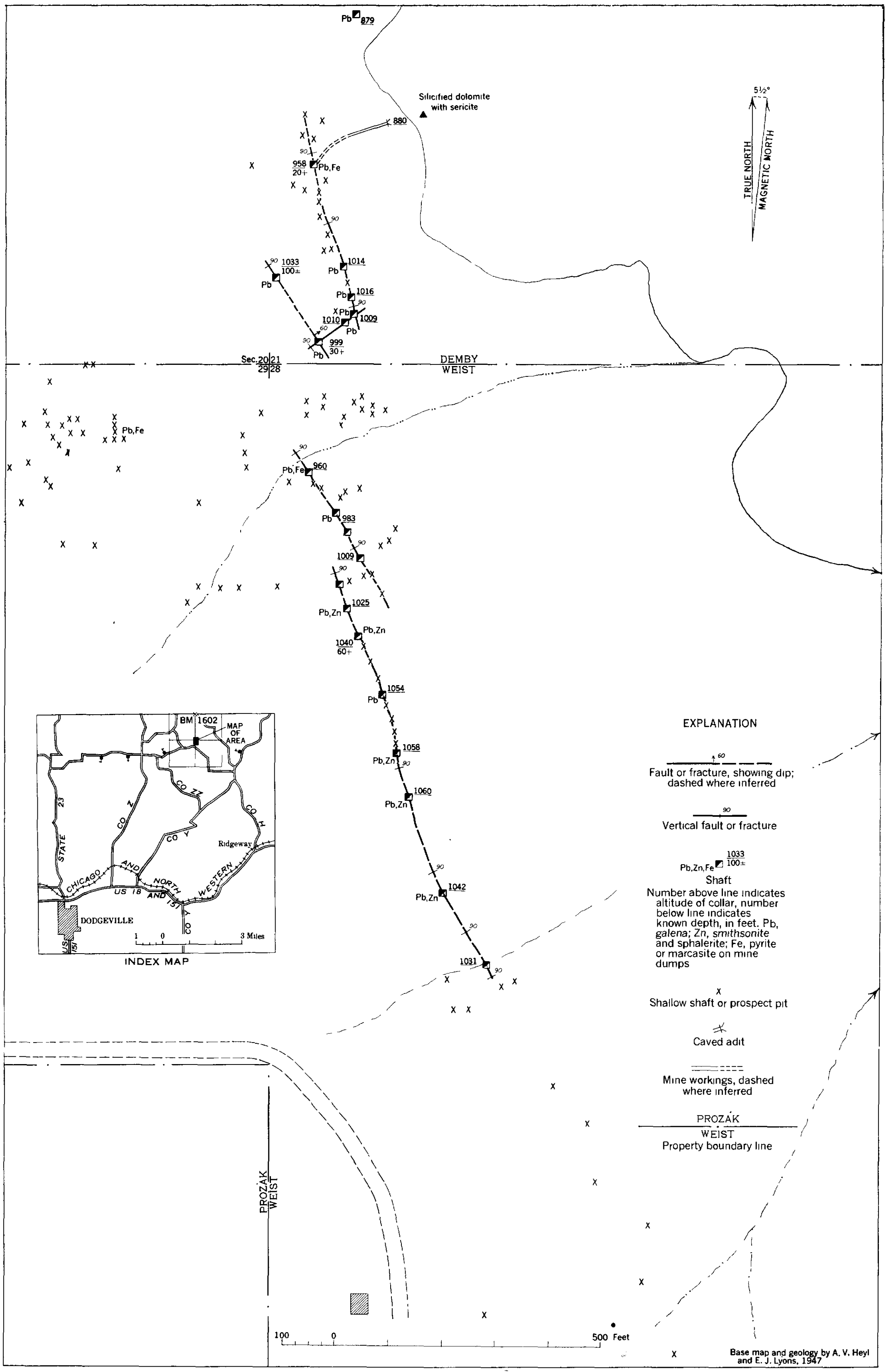


FIGURE 99.—Map of Demby-Weist mines.

corner of sec. 21, T. 7 N., R. 4 E. The workings are along a northerly line more than 2,000 feet long, and are opened by numerous shafts, some of which are more than 80 feet deep. An adit at the north end is now caved. The mines were probably worked between 1880 and 1890 by a Mr. Demby, and a Mr. King from Highland, Wis. Little is known of their history except that a large tonnage of lead ore was produced from them. Most of the stopes are narrow and extend along the controlling fractures.

The lead-zinc ore is in veins and lodes in vertical or steeply dipping faults or fissures. Some of the faults and mineralized gouge zones within them are 10 feet wide. Four main fissures strike N. 15°–30° W. and are arranged in echelon. A few other fissures strike N. 60° E. All of them have smooth walls and are filled with gouge, which suggests that notable movements have taken place along them. The fault pattern suggests that they are a near-surface reflection of an underlying deep-seated north-striking fault in the Precambrian basement, along which lateral movements were renewed in post-Ordovician times. The galena was deposited after movements along the fissures had ceased. These deposits are unusual for the district, but they are structurally like the fissure-vein deposits that are so common in the western United States.

The galena is in coarsely crystallized measures in veins and lodes in the Praire du Chien group and in the Jordan sandstone member of the Trempealeau formation. Abundant smithsonite, with some marcasite, limonite, traces of sphalerite, and much quartz in the form of jasperoid, chert, and drusy quartz accompany the galena. The ores are partly oxidized as deep as they have been explored (about 100 feet).

The Pairie du Chien strata have been brecciated and silicified in the veins and near them. Small pearly white flakes of sericite were noted in cavities and small fractures in outcrops of silicified dolomite near the mouth of the adit.

Lead has been mined from similar deposits from several other places in the vicinity, all in T. 7 N., R. 4 E.: (1) SE¼SE¼ sec. 17, where smithsonite is fairly abundant with the galena; (2) just north of the center of sec. 21; (3) in the SE¼SE¼ sec. 21; and in the NE¼ NW¼ sec. 29, where the galena is accompanied by abundant pyrite and marcasite in a breccia cemented by quartz veinlets.

MONTFORT SUBDISTRICT

The Montfort subdistrict (pl. 1) includes about 6 square miles. Most of the lead mining was done in the nineteenth century within the present town limits and in an area about a mile to the east and half a mile to the north of the town (Hotchkiss and Steidtmann, 1909). Considerable drilling for zinc was done in the area during the period 1900 to 1910, but only two zinc ore bodies of any size have been developed, and these were operated before 1915. The only recent work done in the subdistrict is some prospect drilling (Heyl, Lyons, Agnew, 1951). To the south and southeast the subdistrict is connected with the Mifflin-Cokerville subdistrict by widely scattered lead mines and zinc prospects. About 2 miles north of Montfort is the Centerville part of the Highland subdistrict, from which it is separated by the deep, eastward-trending valley of a branch of the Blue River.

All of the workable deposits in the subdistrict are of the Galena, Decorah, and Platteville formations, but zinc and iron minerals have been located by drilling in the Prairie du Chien group and Franconia sandstone. The zinc ore bodies are mostly replacement deposits that are controlled by bedding plane fractures and incipient pitches. The lead ore bodies occur as gash-veins in joints and openings, as elsewhere in the district. Barite is a common constituent of the ores, and locally marcasite and pyrite are the principal minerals in the veins, sphalerite and galena are subordinate.

The uppermost beds of the Galena dolomite have been removed by erosion. Locally, in the deeper valleys of the southward-extending branches of the Blue River in the northern part of the area, the full thickness of the St. Peter sandstone and the topmost beds of the Prairie du Chien group beneath are exposed (Grant and Burchard, 1907). The Spechts Ferry shale member is 2 or 3 feet thick and the Quimbys Mill member of the Platteville formation is of about equal thickness. The other marker beds are similar in thickness and lithology as they are elsewhere in the district.

The area shows nearly a minimum degree of tectonic deformation, although a little more than in the Dodgeville subdistrict to the east.

Johns or Montfort or Jones and Snow mine (*pl. 1, no. 291*).—This mine is in the S½SE¼ sec. 26, T. 6 N., R. 1 W. Operations began here for iron sulfide ore about 1894, continued intermittently until 1903, and then steadily until 1906 (Bain, 1906, p. 116–117). In the latter period the mine was operated by the Mifflin and Linden Mining Co., a subsidiary of the New Jersey Zinc Co. The ore was shipped to Mineral Point where it was used to make sulfuric acid. The ore body is opened by numerous 40- to 60-foot shafts.

The pyrite and marcasite ore is found as a horizontal vein at the top of the Spechts Ferry member, possibly along a bedding-plant fault. Some of the ore contains considerable quantities of galena and sphalerite, which were recovered as byproducts.

O. P. David mine (pl. 1, no. 293).—The O. P. David mine (fig. 100) is south of the center of the S½ sec. 30, T. 6 N., R. 1 E. The mine was opened by the O. P. David Mining Co. in 1907 after the ore body had been discovered by drilling in 1906. It was operated in 1907, shut down in 1908, and then operated later by the Hump Development Co.

This large isolated mine is reported to have produced about 120,000 tons of zinc ore ranging between 3 and 6 percent zinc. The milling methods were apparently poor, and the losses were high; the jig tailings that remain may average as much as 3 percent zinc. To 1912 about $135,000 worth of ore was mined from the ore body, and in general the mine was a profitable venture. The jig concentrates ranged between 25 and 56 percent and in 1912 averaged 46 percent zinc. The mine roof is very unsafe, particularly at the southeast end.

The entire ore body is in the Guttenberg and Quimbys Mill members and is stoped only about 6 feet high. The ore is in thin veins and disseminated crystals in the Guttenberg member. It is reported that the main eastward-trending part of the ore body is controlled by a pitch that strikes N. 80° E. and dips north. The ore is very lean in iron sulfide, and is accompanied by much barite.

It is reported that the heading 320 feet southeast of the main shaft contains ore, which was left because of the poor roof conditions. The extreme northeast heading may also still be in ore. The Geological Survey drill hole (Heyl, Lyons, and Agnew, 1951, p. 23–24) penetrated zinc ore, which is very probably in the same ore body about 800 feet east of the mine. The same drill hole cut a little sphalerite in the Prairie du Chien group, and a little sphalerite and much marcasite in the Franconia sandstone.

United mine (pl. 1, no. 292).—This prospect is in the NE¼SE¼NE¼ sec. 26, T. 6 N., R. 1 W. The United mine was an operation conducted by the United Mining and Construction and Manufacturing Co. about 1906.

A shaft 91 feet deep was sunk and a little drifting done. Later drilling around the old workings showed only a little galena and smithsonite. No production of ore is recorded from this prospect.

Other nearby small mines are the Montfort Mining Co. mine, at the south edge of the town of Montfort, which cut a considerable thickness of lean disseminated sphalerite, pyrite, and marcasite in the shaft, and the Nagle mine, 1 mile east of Montfort, whose total production was three nail kegs of sphalerite; also, in the town of Montfort at the railroad station, the Station mine, a briefly successful producer of disseminated zinc ore operated from about 1905 to 1910.

HIGHLAND SUBDISTRICT

The Highland subdistrict (pl. 1), considerably larger than the Montfort subdistrict, was long an important source of galena, sphalerite, and smithsonite. The subdistrict had active mines from about 1827 to 1931.

The Highland subdistrict includes a main mineralized center of about 11 square miles (Grant, 1906, atlas) with scattered mineralized areas on the tops of ridges on practically all sides. The edges of all of the mining areas are marked in most places by the upper contact of the St. Peter sandstone, which crops out along the large valleys (Grant and Burchard, 1907). In the branches of the Blue River is an area of 1 to 2 square miles in which much lead has been mined from the Prairie du Chien group (Agnew, Flint, Allingham, 1953, pl. 3).

Most workable lead and zinc deposits are in the lower part of the Galena and in the Decorah, and the upper part of the Platteville formations. Most of the beds of the Galena dolomite have been removed by erosion, and locally, on the highest hills, a few gash-vein lead deposits remain.

The Spechts Ferry shale is about 1 foot thick, and the Quimbys Mill member beneath is about 8 feet thick. The rest of the units show no marked stratigraphic changes.

The area shows a minimum degree of deformation, similar to the magnitude of folding in the vicinity of Dodgeville, Wis. Most of the folds, which are very broad and open, have a general N. 60°–80° E. trend; a few trend N. 30° W. (Agnew, Flint, and Allingham, 1953, pl. 3). The folds have amplitudes of 20 to 40 feet.

The sphalerite and galena ore is in veins, replacement veins, replacements, impregnations, and breccia fillings in the Galena and Decorah formations and Quimbys Mill member of the Platteville. The ore averages about 2 percent lead, which is a greater lead content than is normal in the rest of the district. Many of the deposits are oxidized or partly oxidized, and the sphalerite in many places has been altered to smithsonite, or sphalerite and smithsonite are found as mixed ore. Copper is a common constituent of the ores, particularly in the southern part of the subdistrict, and was at one time mined in the center of sec. 8, T. 6 N., R. 1 E. Most of the copper, which was deposited as chalcopyrite, has been oxidized to secondary minerals.

The ore bodies in the Prairie du Chien group are mainly galena, pyrite, and marcasite in replacement crystals in silicified dolomite and as cavity fillings in brecciated zones in favorable beds. Sphalerite is also reported (Agnew, Flint, Allingham, 1953, p. 7–10, 21–37).

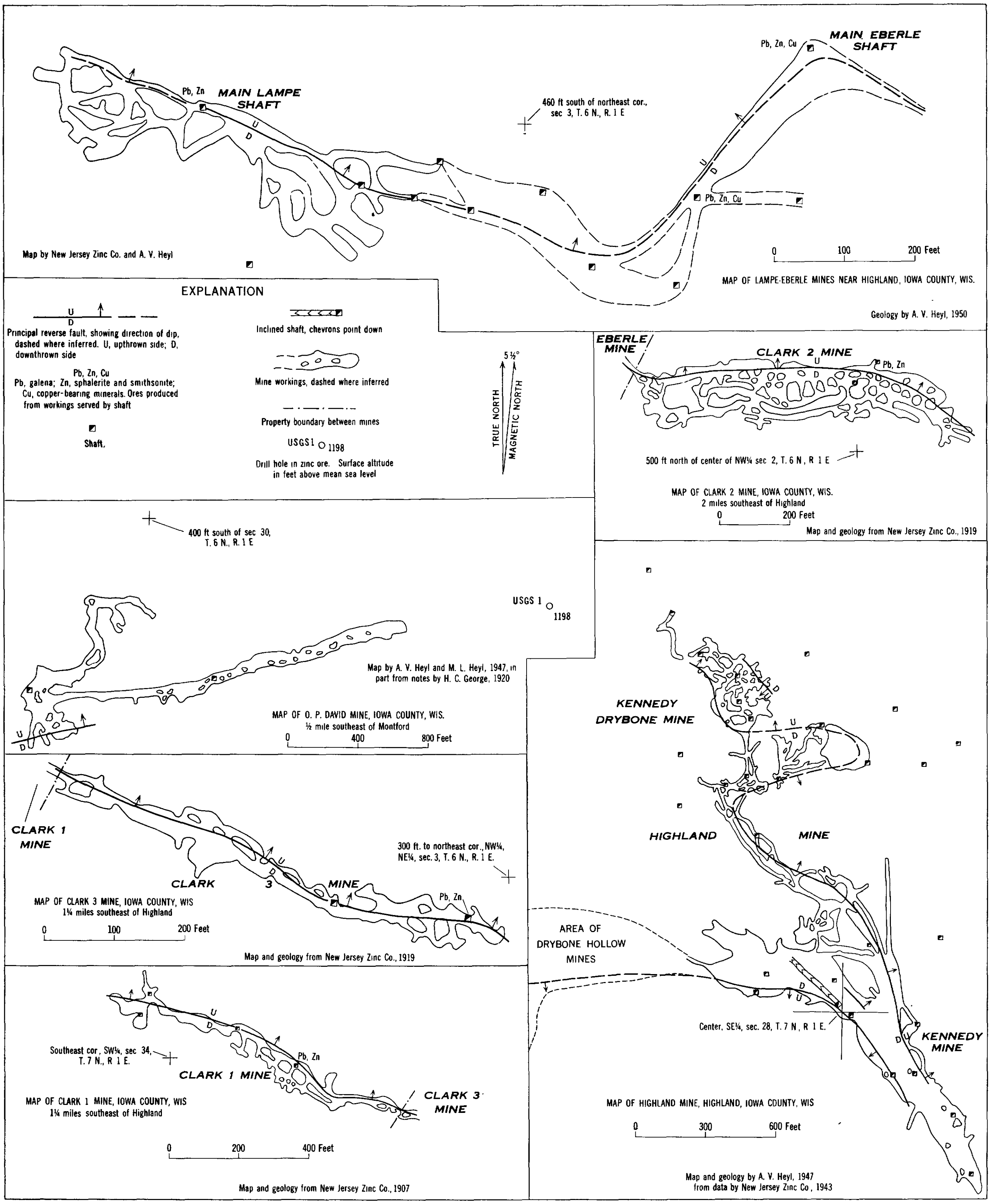


FIGURE 100.—Maps of O. P. David, Lampe-Eberle, Clark No. 1, Clark No. 2, Clark No. 3, and Highland mines.

Red Jacket and Centerville mines, Nundorf diggings (pl. 1, nos. 301 and 302).—The Red Jacket mine is in the NE¼NW¼ sec. 7, T. 6 N., R. 1 E., and the Centerville mine is just a quarter of a mile to the east. In the nineteenth century this property was mined for galena and later for zinc carbonate. Descriptions of the mines in the nineteenth century are given by Whitney (1862, p. 349–350) and Strong (1877, p. 722).

The Red Jacket Mining Co. was formed about 1906 and shipped some ore until after 1910. In 1909 the mine was taken over by the Relief Mining Co. In 1916 and 1917 it was operated by the New Jersey Zinc Co., but was closed because the ore was too low grade and mill recovery was poor. It was reopened and operated on a small scale in 1926 and 1927.

The Centerville mine was opened by the Centerville Mining Co. about 1909. In 1910 it was also operated by the Relief Mining Co. It is probable that the mine was reopened by the New Jersey Zinc Co. in 1916–17 at the same time they operated the Red Jacket mine.

Both mines are in the same sinuous ore body. The ore body forms a broad arc convex toward the north, with the Red Jacket in the west part and the Centerville mine in the east part. The new stopes in both mines are small, and include only a small part of the ore body which had been exploited in earlier times. The Red Jacket stopes have a N. 45° E. trend, are 400 feet long, and 40 to 100 feet wide. The shaft is about 50 feet deep.

The ore occurs in thin veins and disseminations mainly in the beds of the lower Decorah and upper but also in the Platteville, controlled by flats and pitches. The ore is partly oxidized, and a mixed product of about one-half sphalerite and one-half smithsonite was milled. Probably the richer ore was separated by hand sorting. The ore is rich in galena and lean in iron sulfide.

Steppler mine (pl. 1, no. 303).—This mine is in the NE¼ sec. 7, T. 6 N., R. 1 E. The ore body lies just northeast of the Centerville mine and has a general southeast trend. The mine was operated by the Stepplers on a small scale for many years; the last prospecting was done in 1940.

The lead-zinc-copper ore body is nearly half a mile long and averages probably 50 feet wide. It has been worked by numerous shallow shafts about 100 to 200 feet apart.

The principal ores are smithsonite and galena, although sphalerite was mined locally in areas of deeper cover and little oxidation. The ore is found mainly in the Guttenberg, but also in the Spechts Ferry, and Quimbys Mill members, although some was also found in the blue and gray beds of the Decorah formation. Copper in the form of chalcopyrite, chalcocite, malachite, azurite, chrysocolla, and aurichalcite, is found in abundance in the eastern part of the ore body, but it is not known if any was mined.

The western end of the ore body has not been mined, and the Stepplers claim the west mine heading is still good. Here, however, the main ore is probably smithsonite. A dump containing about 6 or 7 tons of smithsonite concentrate remains on the property.

St. Anthony mine (pl. 1, no. 300).—The St. Anthony lead-zinc mine, east of the Steppler, is probably on the same ore body in the southeast corner of sec. 5, T. 6 N., R. 1 E. The alinement of old pits shows that the main ore body has an easterly trend, with branches extending southward to form an arc open towards the north. The mine was operated by numerous shafts, and an adit was driven into the hill from the south. Considerable mining has been done here, but the operation is reported to have been unprofitable. The ores and their occurrence are very similar to those at the Steppler mine.

Kroll mine, Hornswoggle diggings and old St. Anthony mine (pl. 1, no. 299).—The Kroll zinc mine is in the NW¼ sec. 5, T. 6 N., R. 1 E. The old St. Anthony mine is just to the northeast in the southern part of the NE¼NW¼ sec. 5, T. 6 N., R. 1 E., west of the old Hornswoggle (later called Hornsnoggle) diggings which were mined for galena and smithsonite (Strong, 1877, p. 726). The Kroll mine was operated by F. H. Kroll from about 1908 to 1911. An attempt was made to reopen it in 1942, but was abandoned owing to the illness of the operator.

The ore body, marked by shafts and pits, is S-shaped; and trends N. 50° E. at the southwest, or Kroll mine, end; then curves N. 60° W. until it crosses the township road; after which it turns due east through the St. Anthony mine, and then extends eastward through the Hornswoggle diggings (Agnew, Flint, Allingham, 1953, pl. 3). It has been mined for a length of 2,900 feet, to a width of 30 to 100 feet and a height of 6 feet. The main Kroll shaft is 90 feet deep.

The sphalerite ore is found for the most part in the Quimbys Mill member as veins along bedding planes as much as 6 inches thick. Some good-grade disseminated sphalerite ore occurs in the Guttenberg member above.

The ore in the Kroll mine averaged about 8 percent zinc, and this crude ore was concentrated by hand sorting to about 33 percent zinc. It is reported that the southwest heading of the mine is still in good ore.

Ohlerking or Oleking or Moosan mine (pl. 1, no. 309).—The Ohlerking is the principal mine of the many small lead mines in the Prairie du Chien group in the branch valleys of the Blue River southwest of Highland (fig. 1, and Agnew, Flint, Allingham, 1953, pl. 3).

These lead deposits, and particularly that of the Ohlerking mine, have been described and have been long a subject of controversy by geologists and miners as (1) to their potentialities as a source of lead, and (2) the potentialities of the Prairie du Chien group in which they lie as a host rock for lead and zinc deposits of commercial size (Owen, 1840; Daniels, 1854, p. 24; Percival, 1855, p. 66–68, 1856, p. 59–63; Whitney, 1862, p. 410; Chamberlin, 1882, p. 511–517; Ellis, 1904, written communication, p. 23).

The Ohlerking mine, in the NW¼SE¼ sec. 31, T. 7 N., R. 1 E., was opened and operated by Mr. Charles Ohlerking of Highland about 1876 to at least through 1880. The shaft, which starts 45 feet above the base of the St. Peter sandstone, is 175 feet deep into the Prairie du Chien group. A drill hole extends down from the bottom of the shaft 84 feet to the Trempealeau formation. Drifts and small stopes extend about 100 feet northeastward, and probably southward from the shaft at a depth of 90 feet below its collar (Chamberlin, 1882, p. 517).

About 10,000 pounds of galena was mined from the Ohlerking mine up to 1880; thus all the ore and rock removed averaged an estimated 2 percent lead. An additional 8,000 lbs. of metallic lead were produced in the census year of 1880 (July 1879 through June 1880).[4] Daniels (1854, p. 24) states that 200,000 pounds of galena concentrates were produced from the nearby shallow mines in the Prairie du Chien during one season.

Most of the lead ore came from the drifts and stopes in openings that have irregular general northeastward trends in the lower part of the Shakopee dolomite. The openings are nearly filled with reddish clay, decomposing rock and large cubes of galena. Other lead-bearing openings in the Oneota dolomite were penetrated in the shaft. Manganese oxides were cut in "considerable quantity" in the drill hole in the Oneota about 50 feet above the Trempealeau formation.

The ore on the mine dump consists of brecciated, vuggy, silicified dolomite cemented by banded veinlets of comb quartz, the central part of which contain druses of quartz crystals, galena, limonite pseudomorphs after pyrite and marcasite, and a little calcite. Much chert and jasperoid replace the host rocks. The deposits resemble some in the Joplin, Mo., area.

Widely spaced drill holes put down by the Geological Survey in 1950–51 (Agnew, Flint, Allingham, 1953, p. 7–11, 21–37, pls. 3–4) sampled the Prairie du Chien group in several areas west of Highland. Five widely-spaced holes were drilled on a northwest line 400 feet east of the Ohlerking shaft. In some of these holes a little lead, traces of zinc, and much iron sulfide (assayed as much as 12 percent iron) were found showing that the Prairie du Chien is widely mineralized with sulfides in this area. Similar mineralized holes were cut far to the northeast and southwest.

Milwaukee-Highland mine (pl. 1, no. 298).—This small zinc mine is along the center of the north line of sec. 4, T. 6 N., R. 1 E., and extends north into the extreme southeast corner of the SW¼ sec. 33, T. 7 N., R. 1 E. It was operated intermittently from 1906 until 1910. The company was called the Milwaukee-Highland Mining Co. and later the Milwaukee-Mineral Mining Co. The main shaft is 85 feet deep.

It is reported that 52 percent zinc concentrate was shipped in 1910–11.[5] The mine was closed apparently because of the disseminated nature of the ore.

The ore body has a north trend, is 30 feet wide, and follows the west edge of the Highland-Centerville road for 350 feet. At the south end the ore body splits; a narrow, joint-controlled branch extends for about 100 feet to the southwest, and the main part of the ore body extends to the southeast across the property line. The ore is 3 feet thick, disseminated in strata, probably the Guttenberg member.

Wallace mine (pl. 1, no. 297).—The Wallace mine, in the center of the SW¼ sec. 3, T. 6 N., R. 1 E., was operated by the Wallace Mining Co. from 1906 to about 1916, and was reopened and operated briefly by the New Jersey Zinc Co. in 1919. The main shaft is 60 feet deep, and the ore body has a vertical thickness of about 5 feet. The ore is sphalerite and galena disseminated in almost equal quantities in the Guttenberg member; a few small veins were noted. Much of the sphalerite is oxidized to smithsonite. A little chalcopyrite and calcite are accessory minerals. The ore averages 6 percent zinc and yielded a 54 percent zinc concentrate by jigging.[6] The mine was very profitable, and from 1908 to 1910 about $140,000 worth of ore was sold.

Clark mines, including the Cherry Branch, Clark No. 2, Lampe-Eberle, Clark No. 3, and Clark No. 1 mines (pl. 1, nos. 294, 295, 296, and 310).—All of these mines are in the same zinc-lead-copper ore body, which extends along the line between sec. 34, T. 7 N., R. 1 E., and sec. 3, T. 6 N., R. 1 E., and into the northwestern part of sec. 2, T. 6 N., R. 1 E. Starting at the east end of the ore body, the Cherry Branch mine is a small mine to the east of Clark No. 2. The Lampe-Eberle (fig. 100), the oldest, was well described by Bain (1906, p. 116). This description probably fits very well for all these mines. This mine was operated from 1900 to

[4] These additional data are taken from the U. S. Census for 1880 and may include a small part of the 10,000 pounds of ore reported by Chamberlin (1882).

[5] Data provided by C. W. Stoops.

[6] Data provided by New Jersey Zinc Co.

about 1906 as the Eberle mine and after 1906 as the Lampe mine. It was operated by the New Jersey Zinc Co. from 1917 to 1920. The Clark mines were all operated by the New Jersey Zinc Co.; the oldest, Clark No. 1 (fig. 100), operated from 1904 to 1907; Clark No. 2 (fig. 100) operated from 1917 to 1919; and Clark No. 3 (fig. 100) from 1918 to the end of 1919. The Clark No. 1 main shaft is 59 feet deep; the Lampe-Eberle shafts are 63 and 38 feet deep.

The total production from all these mines probably was nearly 400,000 tons of ore that averaged about 5 percent zinc and considerable lead.[7] The possibilities are poor to extend these mines, but possibly some additional ore could be mined from the present workings.

The ore body has a general N. 80° W. trend and is about a mile long, 40 to 160 feet wide, and 7 to 30 feet high. It is controlled by a northward-dipping pitch zone and associated flats. The ore is in all the beds from the top of the Decorah formation downward to the base of the Quimbys Mill member, it is in veins along the pitches and flats and is also disseminated, particularly in the Guttenberg member. Much smithsonite locally accompanies the sulfide ores of sphalerite and galena. Copper ore in the form of chalcopyrite, chalcocite, cuprite, malachite, azurite, melaconite, and aurichalcite is abundant at the Lampe-Eberle mine, and two piles, each containing several tons of high-grade copper ore, remain there. The lead chlorophosphate, pyromorphite, is also found in minute quantities on the Lampe-Eberle dump.

Imhoff mine (*pl. 1, no. 311*).—This zinc prospect, along the center line of the N½SW¼ sec. 35, T. 7 N., R. 1 E., was operated by the Imhoff Brothers on a small scale at intervals from 1904 to 1911. The original shaft, in the northern part of the property, is 115 feet deep. The mine was stoped for a short distance west and southeast from the shaft, but no ore was shipped.

It contains two bodies of ore, an upper one of smithsonite in flats and a lower one in the McGregor that consists of disseminated sphalerite crystals.

Several hundred feet S. 20° E. of the Imhoff mine is a line of three shafts with a drift between the southernmost two. These shafts are a short distance northeast of the Clark No. 2 mine and were mined for smithsonite. A few hundred feet northeast of the three shafts is another shaft 40 feet deep. Apparently very little actual mining was done here, but nine drill holes are reported to have shown good ore. Mining never advanced beyond the development stage.

Imhoff-Egan mine (*pl. 1, no. 304*).—The Imhoff-Egan mine is in the W½SW¼ sec. 27, T. 7 N., R. 1 E. The property was worked from about 1909 to 1912 by the Imhoff-Egan Mining Co. The main shaft is 45 feet deep, to the Quimbys Mill member; the No. 1 shaft is 35 feet deep.

A 40 percent zinc hand-cobbed concentrate was shipped in 1911.[8] About 50 gallons of water per minute was pumped.

The zinc ore body has a general westerly trend but at the west end turns to N. 70° W. It has been mined for 300 feet at a width of about 40 feet. The mine has been worked on two levels about 9½ feet apart, in the blue and gray beds of the Decorah formation, and in the Spechts Ferry member. The best ore is a flat in the Spechts Ferry shale member and along the pitches above. The core area in the footwall side of the pitches is also well mineralized as far as it has been worked. The ore body is controlled by 2 pitches that strike west, and dip to the south. The ore, sphalerite accompanied by some marcasite, is in veins, in replacements, and in cavities in solution breccia. The ore apparently is of a good commercial grade. The mine dump is estimated to average 5 percent zinc. The possibility is good of finding additional ore in the mine and ahead of it in both directions.

Lewis mine, or Lewis and Lynch mine (*pl. 1, no. 305*).—This mine, in the north part of the town of Highland, Wis., along the west edge of the SW¼SE¼ sec. 28, T. 7 N., R. 1 E., was operated from 1892 to about 1905 by the Lewis Brothers and Lynch Mining Co. It lies in a N. 20° W. ore run, and the principal ore mineral is smithsonite, with some accompanying sphalerite and galena. The tonnage mined was evidently very large. A description of this mine is given by Bain (1906, p. 115).

Highland mine, including Kennedy, Kennedy Drybone, Drybone Hollow, Franklin, Old Jack, and North Lewis mines (*pl. 1, no. 306*).—This zinc-lead mine (fig. 100), in the E½ sec. 28, T. 7 N., R. 1 E., is one of the older mines in the north part of the district and grew by gradual coalescence of many older smaller mines. At the west, in the SW¼ sec. 28, the interconnected workings of the very old lead and smithsonite mines of Drybone Hollow extend to the Lewis mines at the south and to the Highland mine at the east. Much smithsonite and galena have been produced from this western area, and in the Highland mine sphalerite was produced as well (Strong, 1877, p. 723–726).

In the early nineteen hundreds the Highland mine was worked by Kennedy and Company of Highland, Wis. The mine was operated by the New Jersey Zinc Co. from about 1906 until 1919, and some additional work was done in the old workings up to 1931 by small

[7] Compiled from data provided by New Jersey Zinc Co.

[8] Data provided by C. W. Stoops.

from the Cassville lead mines, which lie to the northeast, and is probably a part of the same general mineralized center, and therefore they are included within the subdistrict on figure 1.

The deposits are in the middle part of the Galena dolomite and are controlled by vertical mineralized joints that strike between due west and N. 70° W.

The known lead deposits are shown on plate 1. They include: (1) the Panther Hollow mines (Leonard, 1897, p. 51) in secs. 20, 21, 28, and 29, T. 90 N., R. 1 W.; (2) mines in secs. 18, 19, 20, 26, T. 91 N., R. 1 W., all along the Mississippi River bluffs northwest of North Buena Vista; (3) along the south side of the Turkey River, lead mines are south of the river in the N½ sec. 13, sec. 14, east edge sec. 15, and center of the east edge sec. 22, T. 91 N., R. 2 W., known as Lunders diggings; and (4) north of the Turkey River, Burtletts diggings are in the northwest corner of sec. 11 and the N½ sec. 10, T. 91 N., R. 1 W. In the NE¼ sec. 13, T. 91 N., R. 1 W. a mineralized joint was mined for lead at intervals for 1,200 feet, to a depth of 20 or 30 feet, but the ore gave out below that depth.

Fitzpatrick mine (*pl. 1, no. 11*).—The Fitzpatrick mine, in the NW¼ sec. 2, T. 90 N., R 1 W., was operated for lead ore by the Fitzpatrick Mining Co. in 1903 and for zinc ore after October 1, 1904, and was closed in 1907 (Leonard, 1905, p. 300; Bain, 1906, p. 75). The mine was equipped with a 100-ton jig mill, Trego roaster, and magnetic separator. In 1905 about 10 tons of lead ore and 550 tons of 14 percent zinc ore were mined (Bain, 1906, p. 75).

The sphalerite and galena ore is in solution breccia in an opening along a vertical joint and is rich in iron sulfide. At the west end considerable quantities of lead ore were mined at shallow depths.

GUTTENBERG SUBDISTRICT

The Guttenberg mines (pl. 1), the westernmost in the district, are notable for the large size of the galena deposits, which, however, produced low-grade ores. They are along Miners Creek northwest of Guttenberg, Iowa, in secs. 7 and 18, T. 92 N., R. 2 W., and in secs. 11 and 12, T. 92 N., R. 3 W., and were all worked in the Prosser cherty member of the Galena dolomite. The ores contain no zinc, but are accompanied by abundant calcite and some marcasite. The rock is brecciated in zones 3 to 20 feet thick in certain stratigraphic zones; the brecciation is caused apparently by bedding-plane faulting followed by solution. The galena occurs as disseminated cube-octahedral crystals associated with calcite and marcasite, all minerals cementing the fragments of the fault breccia. Some barite accompanies the ores, locally in well-formed crystals. There are no strong vertical fissures in the ore bodies, and in some respects the deposits resemble the bedding-plane fault deposits of the Dodgeville area, Wis. The deposits were last operated in the early nineteen hundreds, although they have been prospected unsystematically in recent years.

Holmes and Kann mines (*pl. 1, nos. 13 and 12*).—The Holmes lead mine is in the SW¼ sec. 7, T. 92 N., R 2 W., about 2 miles west of Guttenberg. The mine is opened by an adit, now caved.

In this old mine the galena is disseminated in horizontal zones up to 50 feet wide, 2,000 feet long and 20 feet high. The ore occurs in the lower Prosser cherty member of the Galena formation. No joints were seen parallel to the east trend of the ore body, though transverse joints contain some ore.

About half a mile farther west is the older Kann mine, which operated about 1860. The stopes, supported by rock pillars, are reported to be 1,800 feet long, 3½ feet high, and as much as 300 feet wide. The mine is opened by an adit, now caved. Unsuccessful attempts to reopen both mines were made in the period from 1948 to 1952.

The ore is in brecciated dolomite as crystals of galena accompanied by abundant crystalline calcite, a little clear barite in crystals, and a little marcasite.

The large tonnage of lead ore formerly produced from these mines, the easy access by adits, and the fact that the area was never thoroughly prospected suggest that future prospecting in the subdistrict would be of value.

MINES IN OUTLYING AREAS OF THE DISTRICT

The mines and prospects of the outlying parts of the upper Mississippi Valley district are mostly widely scattered and isolated deposits that occur at intervals for many miles on all sides of the main part of the district (fig. 101). In a few places the deposits are in clusters, or subdistricts, notably near Wauzeka, Black Earth, and the Demby-Weist mines (pl. 1) northeast of Dodgeville, Wis.

Most of the outlying deposits were worked for lead or iron, or copper, but a few contain zinc, and one is a gold prospect. Most of them are very small mines and prospects, but three, at least, were successful operations of considerable size, namely the Lansing lead mine near Lansing, Iowa, the Demby-Weist lead and zinc mines, and the Ironton iron mine.

Nearly all the outlying deposits that are north of the main district are in the Prairie du Chien group or sandstone of Cambrian age; the outlying deposits to the south are mostly in the Galena dolomite or the basal beds of the Maquoketa shale; those to the southwest are in the dolomite of Silurian age.

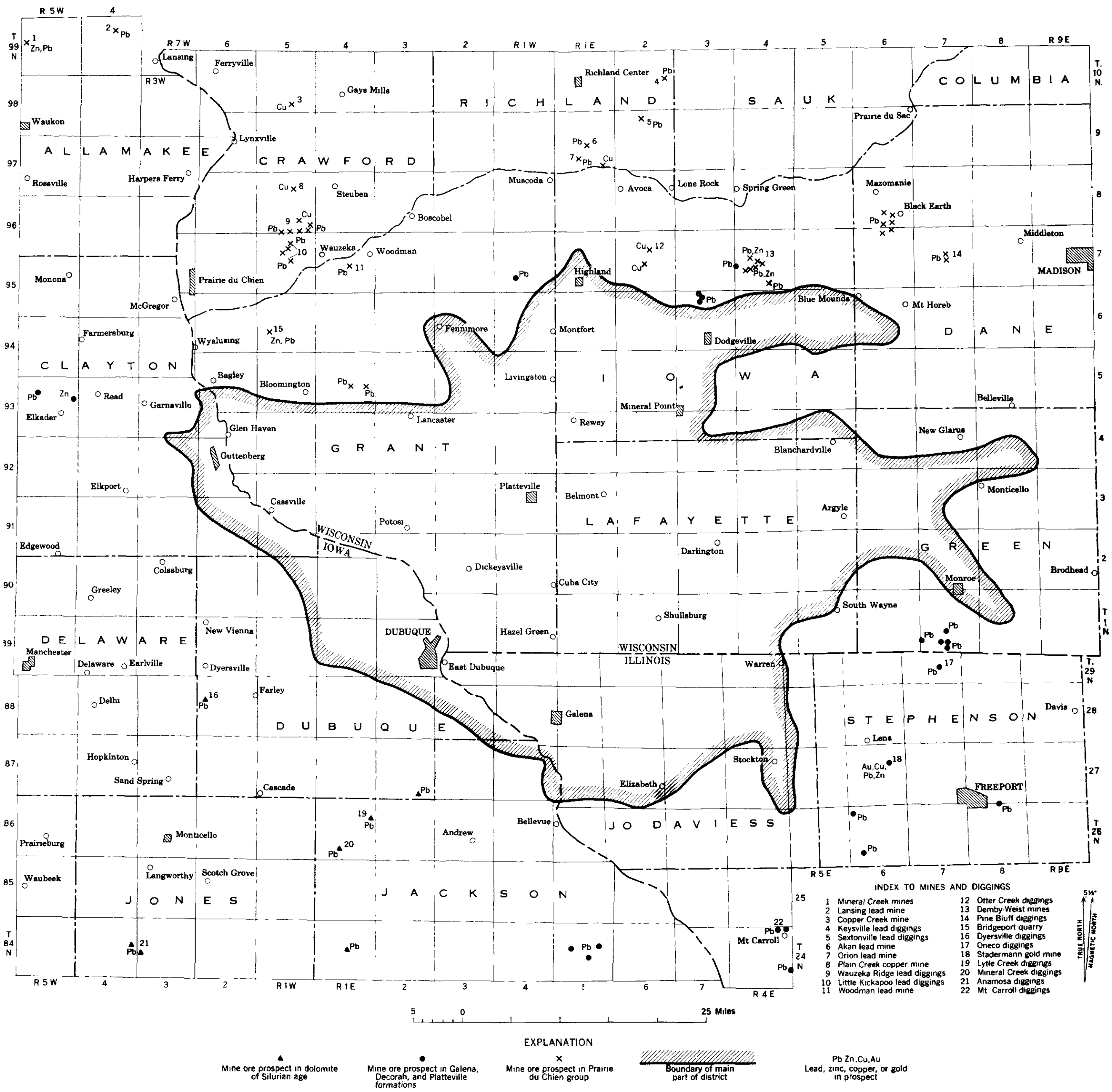


FIGURE 101.—Map showing mineral deposits in the outlying parts of the district.

MINES AND PROSPECTS IN ILLINOIS

MOUNT CARROLL AREA

Small tonnages of lead ore were mined from adits in the walls of the deep canyon of Carroll Creek (fig. 101), where it passes through the north part of the city of Mount Carroll (Willman, Reynolds, Herbert, 1946, p. 9). The ore is in gash veins and openings in the upper part of the Galena dolomite.

FREEPORT AREA

A small deposit of lead ore was mined just east of Freeport (pl. 1; fig. 101) along Yellow Creek, but the history of the mine is not known (Willman, Reynolds, Herbert, 1946, p. 9). The ore is in limestone or dolomite of Middle Ordovician age.

ONECO DIGGINGS AREA

Several areas of old lead mines are located near Oneco, Ill. (pl. 1; fig. 101). Others are to the north in Wisconsin. These very old lead mines were probably first worked about 1800 as the first request for a mineral lease to the U. S. Government was in this area. They were abandoned very early and little is known of their production, except that it probably was not large. The deposits are of the gash-vein type and are in the Galena dolomite.

ELEROY AREA

Stadermann gold mine.—On the Willard Stadermann farm at Eleroy, Ill., a shaft was sunk in a small northward-draining valley, on the north slope of Erin mound about a quarter of a mile west of the Stadermann farm house (SW¼NE¼ sec. 14, T. 27 N., R. 6 E.). This deposit, described by Hershey (1899, p. 240–244), was visited by one of the authors in September 1944.

The shaft was originally sunk 35 feet deep for lead, and penetrated Maquoketa shale and the topmost beds of the Galena dolomite. The rock is reported to be mineralized with pyrite, galena, sphalerite, native copper, barite, chalcopyrite, and pinkish gold-bearing quartz. The galena, sphalerite, and barite are reported as small veins and lenses in the basal beds of the Maquoketa shale. Samples saved by Stadermann indicate that it was a typical vein ore of good grade, but Stadermann stated (1944) that mineable quantities of this material were not present. The fossiliferous layers of the depauperate zone at the base of the Maquoketa shale are almost completely pyritized. Above the lead and zinc mineralized zone is a 6-foot zone of gray-black carbonaceous shale in the Maquoketa that was later mined for paint filler. This shale mining was continued successfully for some time, and one drift was extended for 300 feet to the southwest of the shaft.

Gold-bearing quartz veins are said to be associated with ankerite nodules in a 1-foot layer of massive dolomite just above the 6-foot thick carbonaceous shale bed. No specimens of this material were available among the samples kept by Stadermann, but the description of its occurrence checks closely with that of Hershey. The gold is reported to be in minute visible grains in small isolated nodules of a pinkish quartz, apparently as cavity fillings with crystallized ankerite, in this dolomite layer. Samples of this material are reported by Stadermann and Hershey to have contained about 4 ounces of gold per ton.

The Stadermanns made no attempt to mine the deposit for the gold as only a few gold quartz nodules were found. Results of fire assays of ore samples have been previously given (p. 94). Similar small deposits occur in these same beds elsewhere in this general area.

MINES AND PROSPECTS IN WISCONSIN

Little Grant lead diggings (pl. 1; fig. 101).—Two small areas of old lead diggings, in the Prairie du Chien group, are located in the NW¼ sec. 22, W½W½ sec. 24, T. 5 N., R. 4 W. The ore is galena reported to be in vertical fractures asociated with abundant iron sulfides.

Bridgeport quarry (pl. 1; fig. 101).—Lead, zinc, and iron sulfides are in some quantity in the Bridgeport quarry in the SW¼ sec. 20, T. 6 N., R. 5 W. on the north side of U. S. Highway 18.

Sphalerite, pyrite, marcasite, galena, dolomite, quartz, deep green celadonite, and calcite are deposited in brecciated Oneota dolomite. The Oneota is markedly dolomitized by pink dolomite which also lines vugs as small pink crystals. Much of the host rock is replaced and cemented by jasperoid, quartz veinlets, and vugs lined with drusy quartz. In the northeast part of the quarry sphalerite is common as reddish-brown crystal replacements, as crystals lining vugs, and as veinlets in the breccia. It is associated with much pyrite in crystals and grayish fibrous marcasite. A little galena and calcite were noted.

Percival (1856) reports that galena was found in small quantities in the vicinity.

Woodman lead mine (pl. 1, fig. 101).—This small lead mine is in the north end of a hill in the NE¼NW¼ sec. 27, T. 7 N., R. 4 W. Several shallow pits, shafts, and drifts follow fractures and brecciated areas in the Prairie du Chien group along which galena and calcite were deposited. The host rock is markedly silicified by jasperoid.

Little Kickapoo lead diggings (fig. 101).—Many shallow shafts and pits for lead are in the SE¼ sec. 9, NW¼ sec. 10, and the S½ sec. 15, T. 7 N., R. 5 W. (Owen, 1848, p. 23; 1852, p. 63; Strong, 1882, p. 69–78). Some of these workings are probably old Indian mines.

The principal mine is the Little Kickapoo lead mine (Strong, 1882, p. 69–78), which was worked again during the nineteenth century and some lead was produced. The shallow shafts and pits are a short distance south of Kickapoo Caverns, and the ore is in the upper part of the Oneota dolomite. Galena is deposited in large crystals and masses in silicified and brecciated dolomite. Much jasperoid and drusy quartz is associated with the galena.

The following old lead mines are similar to the Little Kickapoo diggings and are just noted.

Wauzeka Ridge lead diggings (fig. 101).—South parts of secs. 33, 34, 35, T. 8 N., R. 5 W. (Strong, 1882, p. 69–78; Owen, 1848, p. 23).

Plum Creek copper mine (fig. 101).—This copper mine is located in the SE¼SW¼ sec. 26, T. 8 N., R. 5 W. The mine was opened by some men from New York in 1860 and closed in 1861.

The workings consisted of several of many shallow pits and an adit 200 feet long connected by a shaft from above.

In 1947 and 1948 the owner of the mine opened an agricultural lime quarry at the site of the old mine and in the process of quarrying sorted copper ore from the rock. Later, after 1950 he did additional prospecting.

The total production of the mine is probably about 65 tons of ore that averaged between 10 and 20 percent copper (Strong, 1882).

The ore is in masses and veinlets cementing Oneota dolomite breccia. Chalcopyrite and pyrite and marcasite were the primary minerals. Chalcocite, tenorite, malachite, limonite, and copper pitch are the main secondary minerals.

Copper Creek mine (*fig. 101*).—This mine is located three-quarters of a mile west of Mount Stirling, Wis. The mine operated in 1843 to 1847, and again in 1856. It produced about 40 tons of ore that contained probably about 20 percent copper (Strong, 1882, p. 70–71; Owen, 1852, p. 54).

Geologically the deposit is very similar to that of the Plum Creek mine, and is in the Oneota dolomite.

Similar copper deposits are located in the following places:

Readstown copper diggings.—Located in the NE¼ sec. 35 and SE¼ sec. 34, T. 12 N., R. 4 W. (Strong, 1882, p. 72).

Cashton copper occurrence.—Located in the SE¼ sec. 17, T. 14 N., R. 3 W. (Strong, 1882, p. 72).

Brown's farm copper occurrence.—Located in the town of Webster, T. 13 N., R. 3 W. (Strong, 1882, p. 72).

Avoca copper occurrence.—Located in the SE¼ sec. 35, T. 9 N., R. 1 E., north of Avoca (Strong, 1882, p. 56). The deposit is in sandstone of Cambrian ore.

Orion lead mine (*fig. 101*).—Located northeast of Orion, Wis., in the NE¼SW¼ sec. 28, T. 9 W., R. 1 E. This small mine is described by Strong (1882, p. 73–75) and Murrish (1871, p. 42). It produced 6,300 pounds of 70 percent lead concentrates, mostly from the main 86-foot shaft sunk in the middle part of the Prairie du Chien group. The ore is in openings and the rock silicified. Small streams to the east contain placer galena in masses up to 2 inches in diameter.

The following localities are little more than prospects in the Prairie du Chien group in which a little galena was found.

Akan lead mine (*fig. 101*).—Located in the NE¼-NW¼ sec. 22, T. 9 N., R. 1 E.

Sextonville lead diggings (*fig. 29*).—Located in the SE¼ sec. 4, T. 9 N., R. 2 E.

Keyesville lead diggings (*fig. 29*).—Located in the SE¼ sec. 14, T. 10 N., R. 2 E.

Pine Bluff lead diggings (*pl. 1, fig. 101*).—Located in secs. 15, 22, T. 7 N., R. 7 E., Dane County, Wis.

Black Earth lead diggings (*pl. 1, fig. 101*).—Located west and south of Black Earth, Dane County, Wis. These and the Pine Bluff diggings are very old mines worked about 1828 (Chandler, 1829).

Rio lead diggings, Columbia County.—Located in T. 11 N., R. 11 E. (Murrish, 1871, p. 42).

Cambria lead diggings, Columbia County.—Located 3 miles south of Cambria, probably in T. 12 N., R. 12 E.

Doylestown lead diggings, Columbia Couny.—Located "near Doylestown". Possibly these are the same as one of the two deposits listed above. Reported to be in T. 11 or 12 N., R. 11 or 12 E.

Several deposits of limonitic iron ore derived from pyrite and marcasite deposits are described by Strong (1882, p. 49–56) in the region north of the Wisconsin river. The largest of these deposits are:

Ironton iron mine.—A furnace was erected in the SW¼ sec. 10, T. 12 N., R. 3 E. and iron ore was mined from sandstone for more than 20 years from a zone 100 or 200 feet below the top of the Cambrian at Ironton, Wis. In 1880 M. K. Doyan operated the mine to provide ore for a foundry, and 8 men were employed. About 11,000 tons of iron metal was produced before 1873 (Strong, 1882, p. 54; Chamberlin, 1882, p. 518–520) In 1880 this mine produced 2,240 long tons of goethite ore that contained 40 to 50 percent iron, which was valued at $3,000 (U. S. Census, 1880).

Hagerman Hill hematite deposits.—A deposit similar to that at Ironton was mined on Hagerman Hill, about 1875 to 1880, a mile and a half southeast of LaValle, Wis., in sec. 34, T. 13 N., R. 3 E. Ore like that at Ironton is associated with indurated and brecciated sandstone of Cambrian ore, which is also impregnated with malachite and chalcopyrite (Chamberlin, 1882, p. 520).

MINES AND PROSPECTS IN IOWA

Anamosa diggings.—Small quantities of galena are widespread in the Silurian dolomites of Jones County. About 1890 approximately 6,000 pounds of galena concentrates were mined in sec. 13, and approximately 5,000 pounds of galena concentrates in sec. 19, T. 84 N., R. 4 W. (Calvin, 1895, p. 110).

Clinton diggings.—Unsuccessful attempts have been made to mine galena from the Silurian near the city of Clinton, Clinton County (Calvin and Bain, 1900, p. 498; Bain, 1906, p. 66).

The Lansing lead mine.—This mine, in the NW¼ sec. 18, T. 99 N., R. 4 W., just northwest of the town of Lansing, is probably the most productive deposit in the Prairie du Chien group and Trempealeau formation. This mine has been described by Calvin (1894,

p. 105–107); Jenny (1893, p. 211–212, 644); Leonard (1896, p. 53–56); and Whitney (1858, p. 460). The mine operated from 1893 to sometime after 1895 and had produced 500,000 pounds of galena and cerussite concentrates by 1895 (Leonard 1896, p. 53–46).

The ore occurs in a north-trending vertical fracture that contains lead ore in commercial quantities for a distance of 1,200 feet. The fracture was traced the full length of the mine, and to a depth of at least 75 feet. This fracture, according to Jenny, is a fault.

The lead ore, which is in a vertical vein from 3 to 4 inches thick, is galena at depth, but is mostly cerussite at the surface. The vein is bordered by bands of ferruginous clay jasperoid, and chert nodules. The clay has been produced by decomposition of the dolomite wall rock. The vein continues to a depth of 25 feet to 30 feet, but at greater depth the galena is in scattered crystals, which continue to within a few feet of the top of the sandstone of Cambrian age. In the north part of the ore body this type of ore extends downward into the sandstone.

The galena in the Lansing mine contains 4 ounces of silver to the ton, according to Leonard, and 2.6 ounces according to Jenny; it is thus much richer in silver than most galena in the district.

The Mineral Creek mines.—Galena, as small crystals in veinlets in brecciated Oneota dolomite, was formerly mined at the small settlement of New Galena on a branch of Mineral Creek, sec. 13, T. 99 N., R. 6 W., 6 miles northwest of Waukon, Allamakee County, Iowa (Calvin, 1894, p. 104–105). Although there was considerable prospecting and mining, the total production was not more than 100,000 pounds of galena concentrate (Leonard 1896, p. 56–57). The absence of well-defined fractures, the extreme toughness of the rock and consequent difficulty in mining, coupled with the small size of the discovered ore bodies, led to the abandonment of the enterprise.

The area contains lead deposits scattered over at least a square mile in Oneota dolomite, just below the New Richmond sandstone.

Several of the old workings on the Clem Byrnes farm were examined in April 1943 and were still accessible in 1949 through adits. They consist of networks of short narrow drifts which follow zones of greatest brecciation. No regular fracture system was observed. The lead is in the form of octahedral crystals about one-half inch in diameter, scattered within small veinlets of calcite containing some marcasite. Fine-grained reniform sphalerite occurs as small nodular masses in veins. The gangue minerals calcite, jasperoid chalcedony, and drusy quartz have replaced much of the brecciated dolomite.

In the summer of 1943, four prospect churn drill holes were drilled by Charles Youngman; No. 1, 105 feet deep, penetrated mineralized rock in which both lead and zinc combined averaged about 1 percent as galena and sphalerite through a total thickness of 15 feet only a short distance below the New Richmond contact. Holes 2 and 3 were not sampled but No. 4 showed 55 feet that averaged 0.25 percent zinc.

Other outlying localities where lead or zinc have been found in Iowa are: (1) smithsonite in the north part of section 13, T. 93 N., R. 5 W., and galena at old Indian mines 4 miles northwest of Elkader, Iowa, probably in the Galena, Decorah, or Platteville formations. (Owen, 1844, p. 80); (2) old lead prospects on Mineral Creek in dolomite of Silurian age in which about 100 pounds of galena was found in the SW¼ sec. 28, T. 85 N., R. 1 W. (Owen, 1844, p. 71); (3) Lytle Creek diggings in dolomite of Silurian age in the SE¼ of sec. 12, T. 86 N., R. 1 E. (Owen, 1844, p. 84); (4) old lead mines in the SW¼ sec. 15, T. 84 N., R. 1 E. in dolomite of Silurian age; (5) old lead mines in secs. 17, 14, and 22, T. 84 N., R. 5 E. (Owen, 1844, p. 91).

MINE IN MINNESOTA

Dresbach lead diggings.—Galena is deposited in sandstone of Cambrian age at Dresbach, Minn. (Emmons, 1929, p. 255). The ore was mined from "a bed of shale in the St. Croix (Dresbach) sandstone," along a fault that is 4 feet wide at the surface but narrowed below. The fault has considerable displacement, according to Winchell (1884, p. 258). The ore contains galena and pyrite and is disseminated in the country rock on both sides of the fault. Some ore in the fissure cements rock breccia. Galena and cerussite occur in veinlets in Oneota dolomite above the mine. The mine is 200 to 250 feet below the top of the Cambrian.

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Page

Crawhall mine 228
Crooked Six mine 189
Cross folds, nature 55
Crow Branch mine 259-261
Cruson mine 243
Cuba City mine 236
Cultural development 3
Cuprite 88
Curwen mine 205
Curwin mine. *See* Ollie Bell mine.

D

Dall mine 237-238
Dark Horse-Optimo No. 1 mine 272
David mine. *See* O. P. David mine.
Dawson mine. *See* Jack of Clubs mine.
Decorah formation, description 7, 8, 11, 14-16, 17; pl. 2
Defense mine 264
Deformation, single period indicated by cross folding 55
Demby-Weist mines 280-282
Depauperate zone 18
Depp mine 236
DeRocher mine 218-219
D. H. & S. mine 279
Diamond Grove, mines near 270-271
Dikes, sandstone 46
Dodgeville No. 1 mine 279
Dodgeville No. 2 mine 277-279
Dodgeville No. 3 mine 277-279
Dodgeville peneplain 21
Dolomite, deposition of 97
description 90
Dolomitization of calcareous rocks 46
Domes and basins, development 53
Doylestown lead diggings 295
Drab unit 18
Drainage 23-24; pls. 3, 5, 8
Dresbach lead diggings 296
Dresbach sandstone 7, 8
Drift 20
Drilling, critical depth for 170
Drum mine 198
Drybone, defined 165
Drybone Diggings. *See* Little Giant mine.
Drybone Hollow mine. *See* Highland mine.
Dubuque, J., first attempt by white men to mine lead ore 68
Dubuque and Lake Superior mine. *See* Beadle mine.
Dubuque mining subdistrict 289-291
Dubuque shaly member 17
Duke Smith mine. *See* Joe Stegan mine.
Durango Drybone mine 291
Durango No. 1 mine 291

E

Earl mine 267, 268
Earthquake of 1909, importance in the area 54
East End mine 244
East Glanville mine 271
Eastern mining subdistrict 288
Eau Claire sandstone 6, 8
Ebenezer mine 261
Eberle mine, Beetown subdistrict 257-258
Highland subdistrict. *See* Clark mines.
Ed Longhorn mine. *See* New Longhorn mine.
Edgerton mine 247
Edgewood formation 19
Egan mine. *See* Imhoff-Egan mine.
Elements in ore 95
Eleroy, Ill., mines near 294
Elizabeth, Ill., mining subdistrict, location 175
mines in 175-176
Ellis mine. *See* Dodgeville No. 1.
Elmo mine. *See* Beloit-Elmo mine.
Empire mine 248
Empress mine 196
Enrichment, zone of 166-167

Page

Enterprise mine 248
Epsomite 93-94
Ernest and Myers Level 219
Erythrite 93
Etna mine 189
Eureka mine 210
Ewing and Cook mine 194
Ewing diggings. *See* Timber Range mine.
Expansion Level mine 219-220
Expansion mine, of the 1899-1900 period 205, 207
operated by Wisconsin Lead and Zinc Co. 220

F

Facing stone, from the Quimbys Mill member 14
Fairplay Level mine 256
Fairplay mining subdistrict 255-256
Farrey mine 198
Fault-wedge systems 35, 42
Faulting, block 39
Faults, bedding-plane 35-37, 39
major 30, 35-39; pls. 2, 3, 5, 8
minor 39-43, 58-59
normal 35, 42
origin 58-62
reverse 35-37, 39-42
vertical 35, 37-39
Fault zones, Coker No. 2 mine 40, 41
Indian Mound mine 40, 41
Kennedy mine 40-41
Fearless mine. *See* Optimo No. 4 mine.
Federal mine 214
Fenimore mining subdistrict 258
Fever River mine. *See* Depp mine.
Fields-Meloy mine. *See* Meloy mine.
Fields-Thompson mine. *See* Thompson mine.
Fields Upper Run mine 207, 209
Fields mine. *See* Hoskins-Fields mine.
Fitzpatrick mine 292
Flats 39
Flexures. *See* under Folds.
Flotation and new period of rising production 75
Folds, asymmetrical 55
axial-trend relations 31, 32, 34
first-order 27, 28, 29-31, 32, 170-171; pls. 3, 8
importance of, in prospecting for ore 170-172
origin 55-58
regional strike 26
second-order 27, 29, 31-34, 171-172; pls. 5, 8
third-order 27, 29-30, 33, 34-35; pl. 8
Force couples in development of structure, direction of 55
Forest City basin, features 26, 27, 28
Fourteenth Street mine 290
Fox mine 211
Franconia sandstone 7, 8
Franklin mine. *See* Highland mine.
Freeport, Ill., mines near 293
Frontier mine 191

G

Galena, Ill., mining subdistrict, structure 176-178
deposition of 99
description 84, 99, 165-166
Galena dolomite, description 7, 8, 11, 17-18; pl. 2
Galena Level mine 216, 218
Galena mining subdistrict, mines in 178-186
Gash-vein deposits 81
Cash veins of lead ore in joints 43
Geography of the area 3
Geological Survey of the Lead Region, 1839 70
Georgetown syncline, features 30
Germanium production 77
Giles mine. *See* Nip and Tuck mine.
Gilman mine 271
Ginte mine. *See* Graham-Ginte mine.
Glacial deposits 20-21
Glaciofluvial sediments 20
Glanville mine 274
Glanville prospect 176

Page

Glass rock. *See* Quimbys Mill member, Platteville formation.
Glass sand from St. Peter sandstone 10
Glauconite 92-93
Glenwood shale member 7, 11, 12
Goke-Blockhouse mine 243
Gold, assays for 95, 96
native 84
Goslarite 94, 164
Graham-Ginte mine 186
Graham and Stephens mine 247
Graham-Snyder mine 183
Grant County mine 250
Gravity, as force circulating mineralizing solutions 154
Gray beds. *See* Ion dolomite member.
Green rock. *See* Ion dolomite member.
Greenockite 85
Gribble and Stevens mine 271
Gritty Six mine 236-237
Gratiot copper mine 231-232
Gray mine 180
Gray mine. *See* Hughlett and Gray mine.
Great Northern mine 248, 250
Great Western mine 178
Guttenberg limestone member 7, 11, 14, 16
Guttenberg mining subdistrict 292
Gypsum 93

H

Hagerman Hill hematite deposits 295
Haggerty mine 176
Hardy mine. *See* Hofer mine.
Happy Home mine 288
Harmony mine. *See* Treloar mine.
Harris mine 268-269
Harrison Ranges. *See* Liverpool mine.
Hazel Green mine 187-188
Hazel Green-Shullsburg zinc-lead area 186-231; pl. 2
Hazel Patch mine 270
Heathcock mine. *See* Mason mine.
Hecla mine. *See* Calumet and Hecla mine.
Helena-Roachdale mine 219-220
Hematite 88-89
Hematite deposits of Cambrian age 135-136
Hemimorphite 92, 164
Hendy, Gavey, and Sobey & Co. mine 280
Henrietta mine 236
Heyl, A. V., Milton, Charles, and Axelrod, C. E., quoted 94
Hibernia mine 248
Highland mine 287-288
Highland mine. *See* Milwaukee-Highland mine.
Highland mining subdistrict 283-288
Hinkle mine. *See* Robarts mine.
Hird No. 1 mine 191-193
Hird No. 2 mine 200
Hird No. 3 mine. *See* Bearcat mine.
Hi Spot mine. *See* Roseleip mine.
Hoare mine 268
Hodge mine 248
Hofer mine 216
Holmes mine 292
Homestead mine 250
Honessite 94, 96
Honest Bob mine 188
Hoosier mine 183
Hoover mine 194
Hopkinton formation(?) formation 19
Hornswoggle diggings 285
Horseshoe mine 255
Hoskins-Fields mine 197
Hoskins mine. *See* Kennedy mine.
Hoskins mine. *See* New Hoskins mine, Hoskins Fields mine *and* Kennedy mine.
Hospital Run mine. *See* Dodgeville No. 2 mine.
Howe and Alderson mine. *See* Leadmine mine.
Hugh Jones mine 280
Hughlett and Gray mine 184
Hydrozincite 91, 164

I Page

Ida Blende mine. *See* New Ida Blende mine and Old Ida Blende mine.
Illinois, mines and prospects in 175–186, 293–294
Illinoian deposits 20
Illinois basin, features 27, 28
Illinois mine 176
Imhoff mine 287
Imhoff Egan mine 287
Imperial mine 194
Indian Mound mine 207
Ion dolomite member 7, 11, 16–17
Iowa mine 194
Ironton iron mine 295

J

Jack of Clubs mine 200
Jack of Diamonds mine 204
James mine, Hazel Green-Shullsburg subdistrict 220–221
  Meekers Grove subdistrict 239
James Rowe lead mine 231
Jarratt mine 232–233
Jasperoid 91–92
Jefferson mine 187
Jenkinsville mining subdistrict. *See* Meekers Grove mining subdistrict.
Jenney, W. P., quoted 148
Joe Stegan mine 277
John Vivian mine 267
Johns mine 282
Joints, inclined 46; pls. 6, 7
  J_1 group 43–44
  J_2 group 44
  J_3 group 44
  master 45
  north and south 45
  openings in 45
  origin 62–63
  shear 43
  tension 43
  vertical 43–46; pls. 6, 7
Jones and Snow mine. *See* Johns mine.
Jones mine. *See* Karrick mine.
Jug Handle mine 197–198

K

Kankakee arch 53
Kankakee(?) formation 19
Kann mine 292
Kansas mine 176
Karrick mine 290
Kearns mine 193
Kennedy Drybone mine. *See* Highland mine.
Kennedy mine, Hazel Green-Shullsburg subdistrict 211–212
  Highland subdistrict. *See* Highland mine.
Kerrick and Jones mine. *See* Karrick mine.
Kerwin mine. *See* Ollie Bell mine.
Keyesville lead diggings 295
Kickapoo mine. *See* Robarts mine.
Kilbourne mine 290
Kingeter mine 251
Kistler and Stephens mine 244
Kittoe mine 200, 202
Kivlahan mine 190
Klar Piquette mine 244–246
Klondike mine. *See* Little Grant mine.
Kodatz mine 267
Koll mine 234
Krog and Webster mine 254–255
Kroll mine 285

L

Lafayette mine 207
Lafayette mine. *See* Jack of Clubs mine.
LaFollette mine 259
Lake Superior basin 53
Lake Superior mine. *See* Lafayette mine.
Lampe Eberle mine. *See* Clark mines.
Lancaster peneplain 21

Page

Lansing lead mine 295–296
LaSalle anticline, features 27, 28
Last Chance, Hazel Green-Shullsburg subdistrict. *See* Murphy mine.
  Mifflin-Cokerville subdistrict 259
Lateral secretion, defined 148
Lawrence mine, Hazel Green-Shullsburg subdistrict 213
  Meekers Grove subdistrict 234
Lea and Swift's Bone diggings. *See* Quinlan diggings.
Leaching, of primary minerals 164–166
Lead furnaces 69–70
Lead ore bodies, prospecting for 173–174
Leadmine mine 198–199
Leekley Level. *See* Leadmine mine.
Leekley mine. *See* Ollie Bell mine.
Level mine 290
Levens mine 290
Lewis and Lynch mine. *See* Lewis mine.
Lewis mine 287
Liberty mine 234
Limestone beds, alteration by mineralizing solutions 46
Limonite 89, 165
Linden, mines near 271
Linden mine. *See* Mason mine.
Linden Range 272–277
Little Bennie mine 218
Little Corporal mine 182
Little Dad mine 214
Little Dick mine 233
Little Elm mine 239
Little Giant mine 216–218
Little Grant lead diggings 294
Little Grant mine 246
Little Horseshoe mine 255
Little Joe mine 209
Little Kickapoo lead diggings 294
Little Minnie mine 196
Liverpool mine 268
Location of the area 2–3
Loess deposits 20–21
Logan mine. *See* Blain and Logan mine.
Longhenry mine 210–211
Longhorn mine 209
Looney Level. *See* Appleby Level.
Lost Grove, mines near 267–268
Lower Magnesian Limestone of Owen 9
Lower Ordovician series 9
Lucky Five mine. *See* Dodgeville No. 1 mine.
Lucky Four mine. *See* Grant County mine.
Lucky Hit mine 230
Lucky Six mine, Mifflin-Cokerville subdistrict 265
Lucky Six mine, Mineral Point, Linden, Dodgeville subdistrict. *See* Wildcat mine.
Lucky Twelve mine 207
Lyght mine 242
Lynch mine. *See* Lewis mine.
Lyne mine 227

M

McCabe mine 190
McCann mine 190
McFeeley Level 216
McGregor limestone member 7, 11, 14
McKinley mine 279–280
McKinley-Simpson mine 280
McMillan mine 214
McPhee Level. *See* Little Bennie mine.
Madison mine 188
Magmatic hypothesis, areas of similar deposits 157
  causes of precipitation in 162–163
  composition of mineralizing solutions 159–160
  forces motivating circulation 161
  mineral sequence 161
  objections to 163
  return to 150–152
  source of the metals 157–159

Page

Magmatic hypothesis—Continued
  stratigraphic distribution and relations of the ores 161–162
  temperature of ore deposition 160–161
  variations in 148–149
  zoning of the ores 161
Malachite 91
M. and A. mine 262–264
M & D mine. *See* Jarrett mine.
M. and H. mine 247
Maquoketa shale, description 7, 8, 11, 18–19; pl. 2
  prospecting beneath 170
Marcasite, deposition of 98–99
  description 87–88, 98–99, 164–165
Marker strata, use of, in prospecting for ore 168–169
Marsden Black Jack mine 178
Marseilles anticline 53
Martin mine 200
Masbruch mine 236
Mason mine 274
  See also Optimo No. 2 mine.
M.C. mine 252
Meekers Grove anticline, features 27, 29, 30
Meekers Grove mine 237
Meekers Grove mining subdistrict 232–241; pl. 2
Meekers Grove opencut mine. *See* Uniset opencut mine.
Melanterite 94
Meloy mine 197
Mermaid mine 203
Merry Christmas mine 268
Merry Widow mine 182
Meteoric hypothesis, difficulties in 155–157
  discussion of 153–155
  general acceptance of 149–150
  proposal of by Whitney and Chamberlin 148
Michigan basin, features 27, 28
Middie mine 191
Middle Ordovician series 9–18
Midway mine 236
Mifflin-Cokerville mining subdistrict 258–266; pl. 2
Mifflin fault 37, 58; pls. 2, 8
Military ridge, drainage divide 21
Miller mine. *See* Old Grumo mine.
Miller mine. *See* Ollie Bell mine.
Millerite 86, 96, 98–99, 166, 167
Mills mine. *See* Kennedy mine.
Milner mine. *See* Oregon mine.
Milton, Charles, with Heyl, A. V., and Axelrod, C. E., quoted 94
Milwaukee-Highland mine 286
Milwaukee mine. *See* Gribble and Stevens mine.
Milwaukee-Shullsburg mine 231
Mineral Creek mines 296
Mineral point, mines near 268–270
Mineral Point anticline, features 27, 29, 31
Mineral Point-Linden-Dodgeville, Wis. mining subdistricts 266–282
Mineral sequence, in magmatic hypothesis 161
Mineralized area, location 7
Mineralogy 83–138
Minerals, anglesite 93
  ankerite 90
  aragonite 90–91
  arsenates 93
  arsenic 95
  aurichalcite 91
  azurite 91
  barite 93, 99
  bornite 86
  bravoite 88, 166, 167
  cadmium 94–95
  calcite 89–90, 98, 100–101, 166
  carbonates 89–91
  cerrusite 91
  chalcocite 84
  chalcopyrite 86, 166
  cobalt 94–95
  cobaltite 87, 99
  copiapite 94

Page

Minerals—Continued
copper 84
cuprite 88
description 84–94
dolomite 90, 97
epsomite 93–94
erythrite 93
galena 84, 99, 165–166
glauconite 92–93
gold 84, 95, 96
goslarite 94, 164
greenockite 85
gypsum 93
hematite 88–89
hemimorphite 92, 164
honessite 94, 96
hydrozincite 91, 164
limonite 89, 165
malachite 91
marcasite 87–88, 98–99, 164–165
melanterite 94
millerite 86, 96, 98–99, 166, 167
muscovite 92
native elements 84
nickel 94–95, 96
oxides 88–89
phosphates 93
psilomelane 89
pyrite 86–87, 98
pyrolusite 89
pyromorphite 93
pyrrhotite 86
quartz 91–92
safflorite 87, 99
sauconite 92, 164
secondary changes in 164–167
sericite 92
silicates 91–93
silver 95, 96
smithsonite 90
sphalerite 85, 99, 164–165
sulfates 93–94, 164, 165
sulfides 84–88
sulfur 84
tenorite 88
violarite 88, 96, 166, 167
zincian montmorillonite 93
wurtzite 85–86, 99
Minerals of the zinc-lead district, list 84
Mines and prospects, in Illinois 175–186, 293–294
in Iowa 288–292, 295–296
in Minnesota 296
in Wisconsin 186–288, 294–295
Mining, use of structure within ore bodies 174
Mining companies 71, 72, 75
Mining facilities 3
Mining subdistricts, Apple River-Warren, Ill. 176
Beetown 256–258
Blue Mounds 288
Calamine-Truman-Darlington, Wis 251–252
Dubuque 289–291
Eastern 288
Elizabeth, Ill 175–176
Fairplay, Wis 255–256
Fenimore, Wis 258
Galena, Ill 176–186
Guttenberg, Iowa 292
Highland, Wis 283–288
Meekers Grove, Wis 232–241
Mifflin-Cokerville, Wis 258–266
Mineral Point-Linden-Dodgeville, Wis 266–282
Montfort, Wis 282–283
Morseville, Ill 176
North Buena Vista-Turkey River, Iowa 291–292
Pig Patch 241–242
Potosi, Wis 252–255
Scales Mound, Ill 176
Sherrill 291
Simmons Mound, Ill 176

Page

Mining subdistricts—Continued
Stockton, Ill 176
Tete des Morts 289
Minter mine 288
Mississippi River arch, features 27, 28
Mississippi River gorge 23, 24
Mitchell Hollow mines 251
Monarch mine. *See* Sally Waters mine.
Monmouth mine 203
Monroe mine 209
Monsoon mine. *See* Ohlerking mine.
Montfort mine. *See* Johns mine.
Montfort mining subdistrict 282–283
Montmorillonite, zincian 93
Moore Level. *See* Little Bennie mine.
Morrison diggings. *See* Glanville mine.
Morseville, Ill., mining subdistrict 176
Mounds 22–23
Mounds. *See also* Maquoketa shale.
Mount Carroll, Ill., area, mines in 293
Mount Simon sandstone 6, 8
Mulcahy mine 225, 227
Mulcahy mine. *See* Old Mulcahy mine.
Mullen mine 220
Murphy mine, Hazel Green Shullsburg subdistrict 203
Murphy mine. *See* Indian Mound mine.
Murphy mine. *See* Coughlin mine.
Muscalunge Level. *See* Atkinson mine.
Muscovite 92

N

Native elements, description 84
Nebraskan drift 20
Neda formation. *See* Maquoketa shale.
New Birkett mine 202
New Blockhouse mine. *See* Roseleip mine.
New Calvert mine 190
New Cottingham mine 196
New East End mine. *See* Seitz mine.
New Dale Rundell mine 262
New D. H. & S. *See* Dodgeville No. 1 mine.
New Gruno mine 264
New Harty mine 220
New Hoskins mine 196–197
New Ida Blende mine 199
Newkirk mine 288
New Longhorn mine 228
New Lucky Hit mine. *See* Lucky Hit mine.
New McKinley mine. See Dodgeville No. 1 mine.
New Mulcahy mine 221
New Mullen mine 224
New Occidental mine 215
New Rose mine 246
New Strawberry Blonde mine. *See* Strawberry Blonde mines.
New Winskell mine. *See* Wipet mine.
Niagara dolomite. *See* Maquoketa shale.
Nickel 94–95, 96
Nigger Jim diggings 266
Nightingale mine 198
Nip and Tuck mine 219
Noncherty unit 18
North Buena Vista-Turkey River mining subdistrict 291–292
North Langworthy mine. *See* Levens mine.
North Lewis mine. *See* Highland mine.
North Monmouth mine 203
North Rule 275–277
North Star mine 190–191
North Survey mine 277
North Unity mine 183
Northwestern mine 184
Nundorf diggings 285

O

Oakland Level 216
O'Brien mine 224
Occidental mine 210
Okay mine 265–266

Page

Ohlerking mine 285–286
Oil rock. *See* Guttenberg limestone member.
Old Cottingham mine 194, 196
Old D. H. & S. mine. *See* D. H. & S. mine.
Old Gruno mine 265
Old Ida Blende mine 199–200
Old Jack mine. *See* Highland mine.
Old Mulcahy mine 221
Old St. Anthony mine 285
Old Slack mine 265
Old Strawberry Blond mine. *See* Strawberry Blonde mines.
Old Winskell mine 225
Oldenburg mine 182
Oleking mine. *See* Ohlerking.
Ollie Bell mine 204–205
Oneco, Ill., lead mines near 293–294
O. P. David mine 283
Optimo No. 1 mine. *See* Dark Horse-Optimo No. 1 mine.
Optimo No. 2 mine 274
Optimo No. 3 mine 275
Optimo No. 4 mine 275–277
Ordovician system 9–19
Ore, defined 67
Ore bodies, arcuate 109–123
linear 123–128
strawberries, or Strawberry Jack, defined 135
Ore body, B.A.T 124
Coker No. 2 118
Dodgeville No. 1 109
Durango-Drybone 128
Federal mine 120
Fields-Meloy 119
Graham-Ginte 125
Hoskins 119
James 120
Liberty 122
Martin 120
Middle Run 128
Monroe-Longhorn 122
New Birkett 125
New Mulcahy 130
North Monroe 122
Rodham 130
Hazel Green 128
Pittsburg-Benton 128
South Hayden 116
Trego 115
Wipet 122
Ore concentration 71, 72
Ore deposits, secondary changes in 164–167
Ore-lined caves 128
Ore reserves known, 1942–50 72
Oregon dome, features 27, 28
Oregon mine 193
Origin of ores, discussions of 153
summary of concepts 152–153
Orion lead mine 295
Ouachita orogeny, deformation 54
Oxidation, of primary minerals 164–166
Oxides, description 88–89
secondary 164, 166
Oxman and Owens mine. *See* Oxman mine.
Oxman mine 280
Owens mine. *See* Oxman and Owens mine.

P

Paquette mine 230–231
Paragenesis 96, 101
Paul Graber mine 268
Peaceful Valley mine 241–242
Peacock mine 265–266
Pecatonica dolomite member 11–13
Pengelly mine 279
Penitentiary mine 265
Penna-Benton mine 205–207
Percival, James G., quoted 148
Perrot, N., considered discoverer of lead 67
Peru mine. *See* Marsden Black Jack mine.

Page
Pierson prospect 269–270
Phillips and Rice mine. *See* Capitola mine.
Physiography 21–26
Phosphates, description 93
Pilot Knob mine 183
Pine Bluff lead diggings 295
Pine Tree mine 239
Piquette mine 253
Piquette prospect 254
Pitches 39
Pittsburg-Benton mine 189
Pittsburg mine, Galena subdistrict 178
Pittsburg mine, Meekers Grove subdistrict 238–239
Plastic flowage features 47
Platteville formation, description 7, 8, 10–12, 17; pl. 2
Platteville mining subdistrict 242–251
Platteville syncline features 31
Pleistocene epoch 20–21
Pleumer Level 253
Plum Creek copper mine 294–295
P.M. mine 270
Pode mine. *See* Trio mine.
Porter barite mines 241
Porters Grove mines 280
Post-Silurian deposits 19–20
Potosi mining subdistrict 252–255; pl. 2
Prairie du Chien group 8, 9; pl. 2
Prairie mine 275–277
Precambrian rocks 6
Precipitation of ores, from meteoric solutions 154–155
Pre-Illinoian deposits 20
Preston Point Level 253–254
Prospecting methods, correlation of outcrops and drill logs 174
delimiting of ore bodies 174–175
for lead ore bodies 172–173
for zinc ore bodies 172–173
geochemical 174
geophysical 174
older 167–168
Prosser cherty member 17
Psilomelane 89
Pyrite, deposition of 98
description 86–87
Pyritization, term defined 108
Pyrolusite 89
Pyromorphite 93
Pyrrhotite 86

Q

Quarry rock. *See* Pecatonica dolomite member.
Quartz, deposition of 96
description 91–92
Quimbys Mill, member of Platteville formation, description 10, 11, 13–14
minerals in 96
Quinlan diggings 193

R

Raisbeck mine 237
Rajah mine 273
Ralph mine. *See* North Star mine.
Readstown Copper diggings 295
Recent sediments 21
Receptaculites, marker beds containing 168, 169
Red Dog mine 255
Red Jacket mine 285
References 296–303
Reliable mine. *See* Wicklow mine.
Richards mine 214–215
Rico mine 238
Rio lead diggings 295
Roachdale mine. *See* Helena-Roachdale mine.
Road metal, from Silurian rocks 19
Robarts mine 274–275
Robson mine 197
Rockford Mining and Milling Co., mine 176
Rock mine. *See* Winrock mine.
Rodham mine 231
Rolling mine. *See* Optimo No. 3 mine.
Rooney mine. *See* Swift and Rooney mine.
Roosevelt mine 239
Roseleip mine 244
Ross mine 271
Ross mine. *See* Liverpool mine.
Road metal, from Dubuque shaly member, Galena dolomite 18
Rowe mine. *See* Milwaukee-Shullsburg mine.
Rowley mine 215
Royal mine 250–251
Royal Princess mine 180–182
Run, term defined 109

S

Safflorite 87
St. Anthony mine 285
See also Old St. Anthony mine.
St. Peter sandstone 7, 8, 9–10, 11; pl. 2
St. Rose mine 246
Sally Waters mine 205
Sanded dolomite 108
Sanded rocks 97
Sandstone dikes 46
Sauconite 92, 164
Savanna-Sabula anticline, features 27, 28, 29, 30, 55
Scales Mound, Ill., mining subdistrict 176
Scope of the report 5
Schoolcraft, H. R., quoted 68
Scrabble Creek mine 188
Seitz mine 244
Senator mine 264
Sericite 92
Settlement of the area, beginning of 68
Sextonville lead diggings 295
Shalification of calcareous rocks 47
Sherrill mine. *See* Graham-Ginte mine.
Sherrill Mound mining subdistrict 291
Shullsburg mine. *See* Milwaukee-Shullsburg mine.
Shullsburg mining district. *See* Hazel Green-Shullsburg mining subdistrict.
Silicates, description 91–93
Silicification of limestone beds 46
Silicified rock near West Blue Mound, origin 19
Silurian system 19
Silver 95, 96
Silver Dollar mine 273
Silver yield from copper ore 79
Simmons Mound, Ill., mining subdistrict 176
Simpson mine 280
Simpson mine. *See* McKinley-Simpson mine.
Skene mine 176
Slack mine 265–266
Slack mine. *See* Old Slack mine.
Slickensides, as indicators of time of action of forces 63, 110–113
Slobod, quoted 162
Slump of fractures in synclinal areas 46
Smelters near the district 3
Smithsonite 90, 165
Snowball mine 280
Snyder mine. *See* Graham-Snyder mine.
Soft Calvert mine. *See* New Calvert mine.
Solution of adjacent rocks, relation to origin of structures 66
Solution synclines 47
Solution thinning, alteration of limestones and dolomites 46–49
South Rule mine 275–277
South Unity mine 184
Southwestern Wisconsin mine 252
Spargo mine 273
Spechts Ferry shale member 11, 14, 16
Spensley mine. *See* Longhenry mine.
Sphalerite, deposition of 99
description 85, 99, 164–165
Spink mine 241
Spring Hill mine 273
Squirrel mine 265–266
Stalactitic form in marcasite deposits 87–88, 167
Stephens mine. *See* Kistler and Stephens mine.
Stephens mine. *See* Graham and Stephens mine.
Steppler mine 285
Stewart and Bartlett mine 290–291
Stewarts Cave mine 290
Stewartville massive member 17
Stederman gold mine 294
Stockton, Ill., mining subdistrict 176
Stratigraphic distribution of ore, in magmatic hypothesis 161–162
Stratigraphy, as a guide to exploration of ore 168–170
Stratman mine. *See* D.H. & S. mine.
Strawberry Blonde mines 204
Structure, accentuation by solution thinning 46–49
as a guide to exploration of ore 170–172
direction of developing forces 55
origin and mode of formation, previous study on 49–52
origin and mode of formation, proposed interpretation 52
regional relations 11, 26–27, 28, 29
Structures controlling ore bodies, development 63–66
Structures of the mining district 27–49
Structures within ore bodies, use of in mining 174
Sub-Cambrian irregularities 56
Sulfates, description 93–94, 164, 165
Sulfides, description 84–88
secondary 164, 166
Sulfur, native 84
Sulfuric acid plants 80
Surface water, as agency that dissolved minerals 153
Swift and Rooney mine 194
Swift's Bone diggings. *See* Quinlan diggings.

T

Tectonic deformation, relations to solution thinning 48–49
Temby Copper mine 269
Ten Strike mine 182
Tennyson mine 253
Tenorite 88
Terraces, depositional 24–25
erosional 25
Tete des Morts mining subdistrict 289
Thinning of limestone beds by mineralizing solutions 46
Thompson mine 227–228
Thwaites, R. G., quoted 67
Tiffany mine 253
Timber Range mine 291
Tippecanoe mine 246–247
Toadville 242–243
Tommy Dodd mine 187
Topography 21–23
Treganza mine 191
Trego mine, Meekers Grove subdistrict 237
Trego mine, Platteville subdistrict 248, 250
Trego No. 2 mine, Potosi subdistrict 254
Treglown mine. *See* Glanville mine.
Treloar mine 272
Treloar mine. *See* Robarts mine.
Trempealeau formation 7, 8
Trenton limestone. *See* McGregor limestone member.
Trewartha mine 203–204
Trio mine 271
Tripoli mine 270
Tumbled breccias 104
Tunnel Hill mine 214
Turkey River mining subdistrict. *See* North Buena Vista-Turkey River mining subdistrict.

U

Uniset opencut mine 234
United mine 283
Unity mine 184
Upland plain 21
Upper Cambrian series 6–9

Page

Upper magnesian limestone. *See* Galena dolomite.
Upper Ordovician series 18–19
Upper Run mine. *See* Fields Upper Run mine.

V

Valleys 21–22
Vandeventer mine 238
Vegetation 3
Vial mine 272–273
Victory mine 200
Victoria mine 270
Vinegar Hill Blockhouse mine 244
Vinegar Hill mine 183–184
Vinegar Hill Zinc Co., analyses of ore by 95
Violarite 88, 96, 166, 167

W

Wallace mine 286
Warren mining subdistrict. *See* Apple River-Warren, Ill., mining subdistrict.
Washburn mine 259
Wasley Copper mine 269
Water supplies 9, 10, 18, 19
Waters mine 182
Wauzeka Ridge lead diggings 294
Weigle mine 273
Weigle mine. *See* Little Grant mine.
Weiskircher mine 194
Weist mines. *See* Demby-Weist mines.
Webster mine. *See* Krog and Webster mine.
West Empire mine 248
Western mine 270
Western Star mine 247
West Hill mine 247–248
Whaley mine 200
Whig mine 247
Whig Patch area, mines in 246–248
Wicks mine 272
Wicklow mine 233
Wilcox diggings. *See* Black Jack mine.
Wildcat mine 274–275
Wilkinson mine 230
Williams mine 280
Wilson mine 254
Winrock mine 224
Weigle mine 243
Winskell No. 1 mine. *See* Old Winskell mine.
Winskell No. 2 mine. *See* Winrock mine.
Winskell No. 3 mine. *See* Wipet mine.
Winskell No. 4 mine. *See* Lyne mine.
Winskell-Peterson mine. *See* Wipet mine.
Wipet mine 224
Wisconsin, mines in 186–288, 294–295
Wisconsin arch, features 26, 28
Wisconsin deposits 20
Wisconsin dome, features 26, 28
Wishon mine 175
Woodman lead mine 294
Wool rock 18
Wurtzite 85–86, 99

Y

Yellow Jacket mine 257
Yellow sandy unit 18

Z

Zinc ore bodies, prospecting for 172–173
Zinc ores 70, 74, 83
Zinc oxide furnace 70
Zinc smelters 3, 70, 74